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A

SHORT ACCOUNT

OF

SECTION. DIVISION. BOOK.
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AN IMPROVED CANNON,

AND OF THE

MACHINERY AND PROCESSES EMPLOYED

IN ITS MANUFACTURE.

By DANIEL TREADWELL.

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A SHORT ACCOUNT OF AN IMPROVED CANNON.

HAVING been engaged more than four years, in inventing and reducing to practice a method of making cannon of wrought iron and steel, which have been proved, by the most severe tests, greatly superior to cannon made of bronze or cast iron, I have thought that a general account of my mode of operation, and of the principles and laws upon which it is founded, may not be without interest to engineers. Before entering upon a particular account of this improved manufacture,* however, it may be well to examine the qualities essential to all cannon, and to compare with each other the materials which have been hitherto used in their construction. Strength or tenacity, and hardness, are the qualities indispensable to all cannon, and the superiority of one gun over another

* Perhaps the term *useful* may not seem appropriate if used in connection with an improvement in instruments of destruction. The great questions of the evils of war, and its necessity, as connected with the present political and moral condition of man, and of the possibility of attaining a state of civilization and moral improvement which shall establish permanently the relations of peace throughout the world, — questions which are now receiving the attention of many great and benevolent minds, — would be obviously out of place in a paper like this. I take it to be conceded, however, that the history of war has shown that all improvements in its instruments have rendered it less sanguinary.

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is measured by the excess in which it possesses these qualities. Weight, or rather inertia, is likewise required in a certain amount to restrain excessive recoil.

The first cannon made after the invention of gunpowder were of wrought iron. They were commonly formed of staves and hoops, united together by brazing. These engines, it seems, answered for throwing light projectiles, as stone balls, the powder probably being much inferior to that now used with artillery. It is certain, however, that none of the old wrought-iron cannon, made in this way, would withstand a single discharge, if loaded with modern powder and solid iron shot. The early abandonment of these guns, and the substitution of those made of bronze and cast iron in their place, does not prove, however, that the material was inferior to bronze or cast iron, as it is evident that this mode of construction must, in itself, be essentially defective. No fact in the arts seems to be more confidently relied upon, than that wrought iron is much stronger than cast iron or bronze, and this is certainly true if we expose the wrought iron to the testing force in one particular direction only. But all wrought iron is in its structure fibrous, the fibres being more or less distinctly marked, according to the process followed in the manufacture of the iron. In wire it is most clearly apparent, the fibres, in some cases, being so easily parted, that the wire can be split with a knife. In sheets, formed by the rolling-mill, the fibres are arranged in plates or laminæ, and these often so slightly adhere one to another that they may be separated like the layers of a pasteboard. With hammered iron, the

grain, or fibres, are less apparent, and the bars possess, in their different directions, greater equality of strength. By comparing the various operations of wire-drawing, rolling, and hammering, we are led to the conclusion that the fibres are always formed in the direction in which the iron is extended, and the cohesion is least amongst the atoms which are spread over each other. All that is here said of iron is equally true of steel, the cohesive force of which, however, exceeds in an essential degree that of iron. Cast iron and bronze, on the contrary, are of equal strength in all directions; their structure appearing as an aggregation of grains, assuming the form of crystals, often apparent to the naked eye.

The strength or direct tenacity of these various metals, the wrought iron and steel being tested in the direction of their fibres, may be taken as follows for each square inch area of the metal:

Steel (English spring) .	100,000 pounds.
Wrought iron . . .	65,000 "
Bronze	30,000 "
Cast iron	25,000 "

That is, a bar of steel of one inch square will raise and sustain a weight of 100,000 pounds, and bars of wrought iron, bronze, and cast iron, of 65,000, 30,000, and 25,000 pounds, respectively. This statement, supposing all the materials of good quality, is a near approximation to the truth, as derived from the best experiments. If, however, the steel or wrought iron be exposed to the testing force in such a way that the fibres shall be separated laterally instead of being broken, the strength will rarely be found to exceed that of bronze or cast iron, even. This last fact is of

the utmost importance in directing the use of wrought iron, for every purpose, and leads to the direct conclusion, that if a cannon be formed of wrought iron, and the expansion of the gunpowder exert an equal force upon such cannon in every direction, its power of resistance will not exceed that of a cannon of bronze or cast iron, unless the cannon derive, from its peculiar form, an additional strength in some one direction, from presenting a greater section of metal to resist the fracture in that, than in any other direction. Suppose, for example, that we form a hollow globe of fibrous wrought iron, in which the fibres shall pass over the globe in the direction of the parallels of latitude drawn upon an artificial mapped globe. It is evident that an expansive fluid, condensed within the cavity of such globe, will separate these fibres laterally, when its force shall exceed their lateral cohesive power, and if that power do not exceed the tenacity of bronze or cast iron, then its strength will not exceed that of a globe of equal thickness made of either of those materials. By attention to the preceding statement, we see that two distinct questions are brought up for examination. First, Does the expansive fluid, formed of fired gunpowder, exert an equal force in every direction? and, secondly, Does a cannon, of the usual form, present in every direction an equal area of metal, acting with an equal mechanical advantage, to be torn asunder before the fluid can escape? We may, I think, for all practical purposes, take it as true, that the expansive force of fired gunpowder is equal in all directions, and that, consequently, no advantage could be gained by giving any particular direction to the fibres of the wrought

iron of which a cannon should be made, depending upon the force of the fluid being less in one direction than in another.

To answer the second question, namely, Does a cannon of the usual form present, in every direction, an equal area of metal, to be torn asunder before the fluid can escape? we shall find it useful to resort to numbers, and apply them to a form, as an example. For this purpose, let us suppose that we have a hollow cylinder, say twelve inches long, the calibre being one inch in diameter, and the walls one inch thick, giving an external diameter of three inches. Suppose this cylinder to be perfectly and firmly closed, at its ends, by screw plugs, or any other sufficient means. Let this be filled with gunpowder and fired. The fluid will exert an equal pressure, in every direction, upon equal surfaces of the sides and ends of the hollow cylinder. Let us next examine the resisting power of a portion of this cylinder, say one inch long, situated in the middle, or equally distant from the ends, so that it shall not be strengthened by the iron which is beyond the action of the powder. The fluid, inclosed by this ring of one inch long, contains an area of one square inch, if a section be made through it in the direction of its axis; and the section of the ring itself, made in the same direction, will measure two square inches. We have then the tenacity or cohesive force of two square inches of iron in opposition to an area of the fluid measuring one square inch; and if we take the tenacity of the iron at 65,000 pounds, the cylinder will not be burst, in the direction of its length, unless the expansive force of the fluid exceed 130,000 pounds to each inch. Next,

let us suppose a section made through the cylinder and fluid transversely. The area of the fluid, equal to the square of the diameter of the hollow cylinder, is one circular inch, and the area of the whole section is, the diameter being three inches, nine inches. Deduct from this the area of the calibre, and we have eight circular inches. That is, the section of the iron is eight times greater than that of the fluid; whereas in the former case, of longitudinal section, the iron gave but twice as much surface as the fluid, and if we take, as before, the iron at 65,000 pounds per inch cohesive force, it will not be broken unless the force of the fluid exceed 520,000 pounds. It will be found, upon a further examination, that the relations of these sections to each other may be varied, as we take the diameter of the calibre to be greater or less, as compared with the thickness of the sides, but their difference can never be made less than as two to one. Here then is a principle, or rather a fact, of the utmost importance in forming cannon of any material, the strength of which is different in different directions; for as a cannon made in the proportions above specified, if the materials be in all directions of equal strength, will possess four times as much resistance to a cross fracture as it does to resist a longitudinal fracture, it follows, that a fibrous material which possesses four times the strength in one direction that it does in another, will form a cannon of equal strength if the fibres be directed round the axis of the calibre. It is this fact which gives the great superiority to the various kinds of twist gun-barrels. For in these, although the fibres do not inclose the calibre in circles, yet they pass around it in spirals, thus giving their

resisting force a diagonal direction, which is vastly superior to the longitudinal direction in which the fibres are arranged in a common musket-barrel.

Having been aware of the fact here stated, and, I trust, in a manner which can be easily understood and appreciated, for many years, I determined, between four and five years ago, to attempt to apply it, practically, to the fabrication of cannon. My first attempt was to make a four-pounder cannon, by the best means then at my command, of rings, or short hollow cylinders joined together end to end by welding. Each ring was made of several thinner rings, placed one over the other and welded. It will be seen, that, in this case, as the bars of which the several rings were formed were curved round the calibre, the direction of the fibres herein shown to be so essential, was fully preserved. I may remark here, that this method was subsequently changed in some degree, by first making a single thin ring of steel, and upon the outside of this, winding a bar of iron spirally, as a ribbon is wound upon a block. This gun, although imperfectly made, withstood the action of enormous charges of powder, and was only burst by using very superior powder, and shot without windage. The fracture was made lengthwise of the gun, or across the fibres of the iron; and although the welds (technically called jumps), which united the rings to each other endwise, were most imperfect, they yet held together completely against the action of the powder. Two other cannon of similar kind were subsequently made, one of which yet remains uninjured, after having withstood many most severe tests. Having this experimental proof of the strength of cannon made in this

form, my attention was next directed to devising machinery which should enable me to produce guns of large size, with expedition and certainty. The result was, the construction of a hydrostatic press, of fourteen-inch piston, having a power calculated at 1000 tons, and adapting to it a variety of machinery by which the rings can be formed, and afterwards united together, with an ease and expedition, and with a perfection in form and freedom from flaw or blemish, altogether unattainable by any other means; at the same time preserving, in the iron, all its strength and toughness.

A description of this elaborate machinery, and the use of it, would not be intelligible, in detail, without drawings. Nor is it necessary to my present purpose, — which is to show the superiority of the cannon when made, — to say more than that a number of rings or short hollow cylinders are first formed, by means of various moulds, dies, and sets connected with the powerful press before alluded to. The rings are upon their inner sides, and to about one third of their thickness, of steel; the outer portion being of iron, wound about the inner steel ring, and the whole welded together. They are then joined together, end to end, successively, by welding, thus forming a frustum of a hollow cone, the hollow being cylindrical. In giving form to the cone, in the press, its size is determined by a mould of great thickness and strength, which incloses the heated portion of the cone, while a solid mandril occupies the hollow cylinder, the force of the press being applied to sets upon its ends. The pores of the metal are therefore closed, and the metal condensed to a degree not to be attained by the ham-

mer. By turning and boring, this frustum of a cone is formed into the cannon, the breech being closed by a screw plug, and the trunnions fixed upon a band, which is likewise screwed upon the outside of the gun. The trunnion band and trunnions are formed, like the cannon, by machinery moved by the hydrostatic press.

Before I had proceeded to any considerable expense in the construction of this machinery, however, I laid the subject before the Secretary of War, then Mr. Spencer, who very properly referred it to that very competent officer, Lieutenant-Colonel Talcott, Chief of the Bureau of Ordnance. This gentleman, whose knowledge in everything belonging to the use of cannon is probably not equalled, certainly not surpassed, by that of any man in the country, was at first disposed to regard the project with disfavor. He had, several years since, made some experiments in firing a small wrought-iron cannon, made of a large, solid bar of wrought iron, formed under a forge hammer, by a process somewhat like that of common fagoting. This gun, although not burst by the charges to which it was subjected, was sensibly enlarged in its calibre, thus showing that the iron did not possess the hardness required to withstand the enormous pressure of the fluid. On informing Colonel Talcott of my proposed method of manufacture, however, and likewise that it was my intention to make the inner portion of the cannon of steel, he assented to the probability of success, and recommended to the Secretary of War to authorize a contract for a few six-pounder field cannon, which contract was forthwith made. The Secretary of the Navy likewise, Mr. Upshur, directed a

contract to be made for four light navy thirty-two-pounder cannon. These contracts were for cannon for experiment merely; and such was my confidence of success, ultimately, in the manufacture, by the means devised, that I entered zealously upon building the machinery before alluded to, with the necessary furnaces and other works. After about a year and a half of most devoted and exhausting labor, and a very large outlay of money, I completed the six-pounder guns to my satisfaction. They were afterwards proved by officers of the ordnance, and standing the test required by the contract, which greatly exceeded the test of bronze guns of equal weight, 800 pounds, they were accepted and sent to Fort Monroe for further experimental trials. There two of them were fired with service charges, 1,500 times each, without producing any injurious effect upon them. After this, one of those which had withstood 1,500 rounds was proved with the following charges, —

20	rounds	3	pounds	of	powder,	1	shot,	1	wad.
20	"	3	"		"	2	"	2	"
10	"	3	"		"	3	"	2	"
10	"	6	"		"	7	"	2	"

and remains entirely uninjured. There is no enlargement of the bore exceeding $\frac{1}{100}$ of an inch, and the gun is otherwise every way serviceable. No bronze six-pounder gun ever made would withstand, uninjured, a single discharge of three pounds of powder and three shot, and although cast-iron guns are sometimes made to resist that charge, yet the danger from fragments, in the event of bursting, must ever prevent their use with such charges, with any degree of confidence.

During the trials with these guns, at Fort Monroe, I was engaged in making the thirty-two pounders contracted for with the department of the navy. These were finished in November, 1844; and, although their weight was less than 1,900 pounds, the calibres being seventy inches long, one of them bore a succession of charges, commencing with eight pounds of powder and one shot, and ending with twelve pounds of powder, five shot, and three wads. I ought to state, however, that in making some other guns of like size and kind, being unable to procure steel of proper quality for lining their bores, and misled by the extreme hardness of the small guns, I ventured to make them of iron throughout. The consequence has been, that, in two instances, guns similar to those made for the navy, in other respects, on being fired with very high charges, as sixteen pounds of powder, were enlarged by the ball making a lodgment of about $\frac{4}{100}$ of an inch deep, and show a slight starting of the metal upon the external surface corresponding with the point of the lodgment. The use of steel, however, is certain to obviate all imperfections of this kind hereafter.*

* This indentation, or lodgment, seems to be produced, or at least very much increased, by the use of oakum, or other soft wads, placed between the powder and the shot. Whatever hypothesis may be framed to explain the mode in which the wad may be supposed to produce this effect, by its action upon the ball, yet it must be admitted that the subject is very obscure, and perhaps not well understood. Hutton's conclusion, that wads do not prevent the escape of the fluid of the gunpowder, has always appeared to me to have been hastily drawn, although the fact from which he inferred it, namely, that the velocity of the ball is not increased by wads, is fully admitted. It will be readily perceived that the force preserved by the wad, in retaining the fluid behind the shot, must be attended with a loss in the expansion of the fluid into the cavities and pores of the

I have not hitherto spoken of carrying this method of making cannon to those of enormous sizes, such, for example, as shall throw shot of a thousand pounds, perhaps of many tons, in weight. I can see no insuperable practical difficulty, however, to making such guns, by the method devised by me. On the contrary, I can have but little doubt, that further practice will lead to the fabrication of guns of these great calibres, with perfect facility. The efficiency of ordnance of this kind, especially for the defence of harbors, must be apparent at a glance.

On a full consideration, then, of all the facts herein related, it seems perfectly fair to conclude, that cannon may be made, in the method here indicated, which shall combine in half the weight of cast-iron guns, of like calibre, a strength equal to that of the cast-iron guns.

Taking this as true, we are next met with the difficulty of holding such light guns against the tendency of recoil. It must be evident to any one, that the action of the powder upon the shot, is accompanied with an equal action upon the breech of the gun, which produces a forcible recoil of the piece. The whole amount of the force of recoil, with guns of different weights, other things being equal, is in the inverse ratio of the weights of the guns. Now, with guns of cast-iron, of say two hundred times the weight of the shot, it is necessary, when on ship-board, to restrain or check this recoil by some connection of the gun with the side of the vessel. This connection is

wad itself, and in the great friction of the wad upon the surface of the bore. These, taken negatively, may equal the positive loss in escape by windage.

usually made by a very strong rope, called a *breeching*, by which the gun is suddenly, almost instantly, stopped, after it has passed backwards about four feet from the point where it was discharged. In the outset of my experiments, I was sensible, that, unless some more perfect means of governing the recoil than the common breeching was used, the full benefit of lightness derived from the strength of the material could not be obtained. It would be difficult to hold, by the common breeching, guns which should exceed but sixty or seventy times the weight of the shot, when double shotted and fired with full charges of powder. In most of the operations in practical mechanics, the method of destroying the superfluous force of a moving body, is derived from friction. This force, if it may be called a force, has already been applied to check the recoil of cannon, by applying it to a slide upon the carriage, — a method, however, of applying the friction somewhat uncertain, and otherwise objectionable. Considering it of great importance, therefore, to devise some more perfect means of overcoming this difficulty, I was, after numerous experiments, led to construct an apparatus which consists essentially of a shaft passing through the carriage directly under the gun. From this shaft there is passed to the side of the ship, or any permanent object, a large, flat band, made of several ropes, bound together by a weft. Upon one end of the shaft, outside of the gun-carriage, are fixed several small plates or disks. Other stationary plates or disks are placed between these, and the whole are pressed together by a slight spring. The opposite end of the shaft bears a pulley or wheel, upon which

is wound a common rope. Now when the friction-springs are open, if the last-named rope be drawn so as to turn the shaft, the flat band is wound upon it, and by that means the cannon is carried forwards to the position required for firing. Then, by the mere movement of a lever, the springs are suffered to press the plates or disks laterally against each other, and in this condition the shaft cannot revolve, so that the band shall be unwound without overcoming the friction of all the plates which rub each other. This friction may be increased to any amount, either by increasing the force of the springs, or the number of the plates or disks. I have not, perhaps, described this apparatus with sufficient minuteness to render its mode of operation very clear. I can say, however, on full experiments made with it upon a thirty-two-pounder cannon, weighing 1,900 pounds, fired with eight pounds of powder and two shot, the force of the recoil upon the band was no more than 12,000 pounds, a force which does not exceed the strength of one of the ten ropes of which the band is formed. It will be seen, moreover, that with this apparatus, as the gun is carried forward by winding the band upon the shaft, not only the common breeching is dispensed with, but also all the tackle ordinarily used for moving the gun, thus giving a clear deck to the officers and men.

Some objections have been made to this apparatus, on account of a supposed difficulty in managing it readily, by the seamen or artillerists. The same objection may be made to the common gun-lock, because it is more complicate than a match. The same objection was most likely made by the ancient spear-

men against the bow and arrow; and by the latter in turn against the whole apparatus for using gunpowder. It has always been made against new machinery, and has always yielded to the skill acquired by a little time and practice. But, conceding for a moment the possibility that this apparatus cannot be advantageously used, we may yet resort to the common breeching, and obtain a great part of the advantages of these wrought-iron cannon. For, although in this case the force of the recoil may not permit us to reduce the weight to the extent that it might be, if the motion of the gun were restrained by friction, it may still be so reduced as to give advantages, both on sea and land, unattainable by any other means.

That we may understand and appreciate the advantages to be attained by substituting these wrought-iron and steel cannon for those now in common use, especially in the naval service, a brief examination of the past and present batteries of ships of war seems necessary. The guns of the navies of Great Britain, France, and the United States are now, for the most part, thirty-two-pounders, differing somewhat in length and weight, according to the size of the vessel, and the deck upon which they are used. To these are added a few bomb-cannon of eight, and sometimes ten, inches calibre. The importance of throwing shot of the greatest possible size appears to have become more and more apparent for the last hundred and fifty years. About one hundred years ago, Mr. Robbins, to whom the art of gunnery is more indebted than to any man, save the inventors of gunpowder and guns, proposed to the Lord High Admiral of England to enlarge the calibres of all the cannon of the

navy of that country, assuring him that in this way the maritime force would be doubled. The guns then used were nine and twelve-pounders, and as the ships would not carry a greater weight, Mr. Robbins thought it would be advisable to use heavier shot, though it should be necessary, to prevent the destruction of the guns, to diminish the charges of powder. This plan was not carried into immediate effect; but, as ships have been increased in size, the armaments have been altered by giving an additional weight to each gun, rather than by increasing the number of guns, retaining the old calibres.

It has been found by experience, that the destructive effect of large shot, as compared with small, is much more than in the direct ratio of the mass, when the velocities are equal, as a forty-two-pound shot, for example, may often produce more effect than twenty of eighteen pounds; as the latter, from a little want of force, may remain harmless in the side of a vessel, where the former will enter, carrying destruction in every direction. So a small hole made by a shot under water will, from the elasticity of the fibres of the wood, so far close as to prevent any serious leak, while a larger shot will often shatter the plank and timber for a great space about the point at which it strikes. The same is true of the masts and spars. Hundreds of six-pound shot may be fired into a large ship's mast, without essentially weakening it, while a single forty-two-pound ball is likely to destroy it. The effects here stated are supposed to be produced by balls of unequal sizes with equal velocities. This will, however, rarely be the true state of the facts, as the larger shot maintains its high velocity much

longer than the smaller. This arises from the resistance of the air being as the square of the diameter of the projectile, while the force of the projectile is as the cube of its diameter, the body being spherical. It is from the operation of this law that the flight of large shot, and consequently the space through which they pass, is so much longer than those of small shot. A prodigious advantage may be derived from the fact last stated, especially by war-steamers, which can choose and maintain a distance when opposed to sailing vessels. A single steamer, armed with a gun to carry, with a full charge of powder, a shot of two or three hundred pounds, for example, may in this way conquer a ship of the line, armed with an ordinary battery, as a very few shot of this size, perhaps a single one, may sink the largest ship ever yet constructed. Not that the advantage of guns of this large calibre is by any means confined to steamers. With sailing vessels opposed to each other, if the disparity in the size of the shot be great, one may destroy the other at such a distance as to receive no injury whatever from her adversary.

The statements here made are so completely borne out by experience, that Mr. Cooper in his Naval History says, "There is scarcely an instance on record (we are not certain there is one) of a full manned frigate carrying twelves (pounders) prevailing in a contest even with a ship of eighteens"; a very strong statement when we consider the superiority of the officers and crews, as well as of the equipment, except in size of guns, with which the twelve-pounder frigates must sometimes have entered the contest.

These facts are enough to show that an immense

advantage may be attained by increasing the calibres of naval batteries. But the impracticability of obtaining any considerable increase of this kind while cast iron or bronze are used as the material of cannon, will be manifest from a slight examination. Experience has fully shown that from 150 to 200 times the weight of the shot is required in all cast-iron guns of the usual proportional lengths, when used with full charges of powder, to render them secure from bursting; even when of these weights the security is not perfect, as the history of naval battles shows numerous instances of terrible destruction from the bursting of cannon. One of the first guns fired from an American frigate in the war of 1812 burst, and killed and wounded sixteen men; amongst the latter the commander of the squadron himself. This deficiency of strength, then, must prevent any considerable enlargement of the calibres of guns of the weights now used, if made of cast iron. By substituting bronze, perhaps somewhat larger calibres might be given to guns of the present weights, without the great danger from destruction by bursting; as bronze guns generally give signs of their injured condition by showing cracks and enlargements before breaking into fragments. This material, however, is so deficient in hardness, that a few hundred discharges with shot and full charges of powder commonly render the guns unserviceable. We are thus driven to the conclusion that the calibres of navy cannon made of cast iron or bronze cannot be increased without a corresponding increase in the weight of the guns themselves. We come, then, to the question, whether such increase in the weight of the guns is practicable,

and it will be conceded that some small increase in this particular might perhaps be adopted. We have seen, that, in the course of the last hundred years, guns have been increased from nine and twelve to thirty-two and forty-two pounders; and it is by no means certain that the maximum weight is yet attained. It is not probable, however, that it can be carried much farther, as, with their present weight of armament, ships labor very severely in rough weather, and in great gales are necessarily lightened by throwing the guns overboard. Besides this, an increase of weight must increase the labor of working the guns, thus making more men necessary, for which the present decks do not furnish sufficient quarters.

These difficulties, however, all vanish before the use of wrought iron and steel. With cannon of these materials, made after the manner herein indicated, there can be no doubt of the practicability of firing heavy charges from guns having but sixty times the weight of the balls. Let us, then, look for one moment at the advantage which may be derived from such guns in an example. Take a frigate which now carries thirty-two pounders. By the substitution of these cannon for cast iron, this frigate may be armed with sixty-four-pounders, and, without any increase of officers or men, may be made to throw as many shot of this weight, in a given time, as she can now throw of the lighter kind. The result must be, that in force she would be superior to any two-decker, as now armed, which could be opposed to her. Many of the ships and steamers now carry bomb-cannon. These are of great weight, though rarely if ever exceeding ten inches in calibre. The same shot may be thrown

from steel cannon of about half the weight; or wherever guns of the present weight can be carried, they may be made of wrought iron and steel, of increased calibres, sufficient to throw shot and shells of double the weights of those now used. The immense increase of force to be derived from these great projectiles need not be further insisted upon. What, then, is to prevent the government from adopting an improvement which presents such advantages? I am aware that it has been said, that no government can derive any benefit from an improvement which may be adopted by its enemies. This argument lies with equal force against all improvements in war. Forts, ships, and discipline even, must be kept stationary, if it be received as sound; and if the government are prepared to act upon it to this extent, I have nothing more to offer. But I will not suppose that a consideration like this can prevail against any improvement in either the arts of war or peace. Another objection has been made in the great cost of cannon, of the kind here proposed, over those of cast iron. It can, I think, be shown, that, if the facts of superiority, as I have stated them, be true, a nation would gain by the use of these guns, if purchased by a sum equal in value to their weight in silver. I will not here go into the details necessary to show this, but when it is considered that the United States navy now requires six millions of dollars a year for its support, an annual expenditure which represents a capital of one hundred and twenty millions, it will readily be conceived, that if its force can be essentially increased by an improvement in a permanent instrument requiring no annual cost, the price first paid for the improvement can be

of no great importance. Navies are, with all commercial nations, the favorite instruments of war. In the United States, the policy of large expenditures for works to facilitate the construction and equipment of ships has become established. For this purpose, two docks have been built, which alone have cost about $1,600,000, and it is now proposed to build a third. Few persons are found who entertain, for a moment, any doubts of the propriety of these expenditures. Who, then, will hesitate to apply the same liberality to the armament, which constitutes the immediate instrument of naval power? Of what importance, then, are a few hundred thousand dollars, when compared with the object here presented? — presented not in the form of a mere theory, existing only in the mind of an ardent projector, but reduced by years of labor and a great outlay of money to actual practice, in which it has passed the test of most severe and decisive experiments.

Without making a full array of the advantages to be derived from the use of these cannon on land, I will merely allude to the very obvious increase in the force of field-artillery which may be obtained by substituting steel twelve-pounders, for bronze six-pounders, and other changes of like kind for the larger calibres. The use of the common field train for battering cannon would likewise be of great importance; but, more than all this, the confidence of the men in the strength and endurance of their arms may be insisted upon as of incalculable advantage. Suppose an army of infantry armed with bronze or cast-iron muskets, — would they be expected to stand against well-armed enemies? And yet the case is in no wise

different from the present artillery equipment; and, if wrought-iron and steel cannon were now in common use, it would be considered as absurd to propose the use of cast iron in their place, on the score of cost, as it would now be, to propose to change the present muskets for those made of cast iron.

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ON

THE PRACTICABILITY

OF

CONSTRUCTING CANNON OF GREAT CALIBER,

CAPABLE OF

ENDURING LONG-CONTINUED USE

UNDER FULL CHARGES.

BY

DANIEL TREADWELL,

VICE-PRESIDENT OF THE AMERICAN ACADEMY, AND LATE RUMFORD PROFESSOR IN HARVARD UNIVERSITY.

[From the Memoirs of the American Academy.]

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FROM THE

MEMOIRS OF THE AMERICAN ACADEMY.

On the Practicability of Constructing Cannon of Great Caliber, capable of enduring long-continued Use under full Charges.

By DANIEL TREADWELL,

VICE-PRESIDENT OF THE ACADEMY, AND LATE RUMFORD PROFESSOR IN HARVARD UNIVERSITY.

The importance of constructing cannon of a size larger than any now in use, to every nation that may be called upon to encounter the trials of war, is one of those facts acknowledged alike by the soldier and the civilian; and to obtain such instruments, capable of throwing projectiles larger and heavier, and to greater distances, than has hitherto been attained, is now occupying the attention of the scientific engineers and projectors of Europe more than any other question open to them. The present age has witnessed a remarkable increase in the size of all the great instruments of human industry. Ships within twenty years have been doubled in their dimensions, and steam-engines are now constructed which compare with those of the last age as giants compare with common men. But although the want is fully

acknowledged, and attempts have been made in hundreds of forms, no one has succeeded in producing a cannon essentially more powerful than those used in the days of Napoleon and Wellington.

I propose, in this paper, to search for the causes of these failures, to examine the action of the forces, both active and passive, which are called into operation in throwing shot and shells by gunpowder, and, at last, shall endeavor to show that our present cannon do not approach the size and power of those that may be constructed.

I have said that no essential improvement has been made during the present age in the size of cannon. It is true that they have been increased in caliber from seven, up to eight and ten inches, and a few bomb-cannon have been made of twelve inches. But in the use of these the charges are so diminished, to be brought within the limits of safety, that the initial velocities, as inferred from their short ranges, are not so great as those of the old forty-two pounders; while with mortars, those of thirteen inches were used in the time of Vauban, and this remains, stereotyped, as the limit at the present day.

But to my examination. The properties or qualities of hardness and of tenacity or strength are the qualities indispensable to all cannon, and the superiority of one cannon over another is measured by the excess in which it possesses them. Inertia* is like-

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* This word is used throughout this paper in its strictly technical sense, as the force, or power of resisting all change of state,

wise required, in a certain amount, to prevent excessive recoil. Now these properties of strength and hardness are possessed in an eminent degree by bronze and cast-iron, and these bodies alone constitute, in practice, the materials for cannon; for although various attempts have been made to introduce steel and wrought-iron, it is enough for my present purpose to say, that there are not twenty cannon in use in the world, that are not made of bronze or cast-iron. For strength, bronze is generally taken at 30,000 pounds to the square inch; that is, that it will require a weight of 30,000 pounds to tear asunder a bar of good gun-metal bronze of one inch area. Following the mean of many experiments, cast-iron has generally been taken at 20,000 pounds. But that I may be sure not to under-estimate the strength of this material, and as it has been considerably improved by gun-makers within a few years, I shall estimate it at 30,000 pounds, or as equal to bronze, although it is not to be relied upon as so constant in its strength as the latter material. For hardness cast-iron greatly exceeds bronze. This renders it more suitable for very large guns, and it has, in truth, become so exclusively the material for everything above the size of field-pieces, that I shall deal with it alone in the examination proposed in this paper.

Before examining the force of gunpowder it may

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whether it be from rest to motion or from motion to rest; and I use, without a doubt of its accuracy, the square of the velocity by the mass, as the measure of this force.

be well enough to say a word upon the time of its explosion. Is the firing of gunpowder instantaneous? This question has been discussed, and experiments made upon it, by Mr. Robins, Dr. Hutton, Count Rumford, and many others, besides a special committee of the Royal Society. If it be instantaneous, then it must be evident that no other substance can be fired with a greater rapidity. For instantaneousness, bearing the same relation to time, that a point does to space, can admit of no degrees. Both are existences without extension, and we cannot say of any two events that one is more instantaneous than the other, without implying duration to one at least, which also implies that it is not instantaneous. Now many of the fulminating powders, and even gun-cotton, are, as is well known, fired much more rapidly than gunpowder. The firing of this last cannot, therefore, be instantaneous, and we might rest with this logical solution of the question; but, like many other logical solutions, it adds but little to our wisdom, and the amazing rapidity with which a large mass of powder is inflamed, when in a close cavity, awakens our attention to the course of the events causing, or at least accompanying, this inflammation, and I shall notice two experimental results which seem to me to indicate the state of things during that whole course.

First, Count Rumford has proved that the burning of the grains is slow, or that a sensible time is required with each grain before it is wholly converted into the gaseous state; and secondly, various experiments made in England and in Prussia have shown that there is no

sensible difference produced in the velocity of the shot by communicating the fire to the centre rather than to one end of the charge, which ought evidently to take place if the fire is communicated from one grain to another in succession, as this communication, being in both directions, when proceeding from the middle, would require but half the time that is required when proceeding from one end, and ought to produce a sensible increase in the velocity of the shot. I think, therefore, that these two facts warrant the following inference as to the course of the action during the production of the force. When the fire reaches the charge from the touchhole, the nearest grains become kindled; the hot fluid evolved is thrown farther into the charge, and the burning succeeds successively until the pressure becomes so great as to condense the air contained between the grains sufficiently to produce the heat required for firing those grains, which are then consumed more or less rapidly, as they are fine or coarse. We have, then, first the burning in succession of a small part of the charge; then the immensely rapid, though not instantaneous, kindling of every grain composing it; and then the consumption of those grains, which is not accomplished without time. It is a task for the conception to grasp these events, following one another in distinct succession; each having its beginning, middle, and end, and all being comprised in the period of $\frac{1}{200}$th of a second (gun 4 feet long, *formula* $t = \frac{2s}{v}$). When we have mastered the imagination of these, we may go further and combine with them

the connected and contemporaneous action of the ball, which passes from rest to motion, and through every gradation of velocity up to 1,600 feet a second, and leaves the gun as our historical period of $\frac{1}{200}$th of a second expires.

The expansive force of gunpowder, which must be resisted by the strength of the cannon, depends almost entirely upon the circumstances under which it is fired. Count Rumford has shown, by his experiments made about sixty years ago, that if the powder be placed in a closed cavity, and the cavity be two thirds filled, the force will exceed 10,000 atmospheres, or 150,000 pounds upon the square inch; and he estimates that if the cavity be entirely filled with the grained powder, and restrained to those dimensions, the force will rise to 50,000 atmospheres. My own experience, made in bursting wrought-iron cannon the strength of which was known to me, leads me to believe that he has not over-estimated its power, although I am aware that it is generally considered as excessive. If, following an opposite course to that herein described, the powder be at liberty to expand upon any side, the force thrown in the other directions is very small. Thus, if a charge be placed loose in a gun, without shot or wad, the force upon the walls of the gun is very trifling; — no more than is produced by the restraint of the inertia of the charge itself, or the fluid formed from it. If we would divest a charge of this property of inertia, and fire it in a constantly maintained vacuum, it would not rend walls made of cartridge-paper, if a single end

were left open for its escape. From the preceding statement, it will be seen that gunpowder will take any force, from perhaps 50,000 atmospheres, when confined to a close cavity, down to zero, if it be deprived of inertia and fired in a vacuum constantly maintained.

In artillery practice, the restraining power which causes the powder to act against the walls of the cannon is derived principally from the inertia of the shot. This is so much greater than the inertia of the powder itself, that the latter may be neglected in the considerations that are to follow. Now, bearing in mind what has been already said, let us compare the difference of the force of powder as exerted upon a small and a large gun respectively. It is perfectly well known, that, if we have a pipe or hollow cylinder of say two inches in diameter with walls an inch thick, and if this cylinder will bear a pressure from within of 1,000 pounds per inch, another cylinder, of the same material, of ten inches in diameter, will bear the same number of pounds to the inch if we increase the walls in the same proportion, or make them five inches thick. A cross-section of these cylinders will present an area proportional to the squares of their diameters, and if the pressure be produced by the weight of plungers or pistons, as in the hydrostatic press, the weight required in the pistons will be as the squares of the diameters, or as 4 to 100.

Now carry this to two cannon of different calibers, and take an extreme case. Suppose the caliber of one to be 2 inches in diameter and the other 10 inches,

and that the sides of each gun equal, in thickness, the diameter of its caliber. Then to develop the same force, per inch, from the powder of each gun, the inertia of the balls should be as the squares of the diameters of the calibers, respectively; that is, one should be 25 times as great as the other. But the balls, being one 2 and the other 10 inches in diameter, will weigh 1 pound and 125 pounds respectively; the weights being as the cubes of the calibers. Hence each inch of powder in the large gun will be opposed by 5 times as much inertia as is found in the small gun. This produces a state of things precisely similar to that of loading the small gun with 5 balls instead of 1;* and although the strain thrown upon the gun by 5 balls is by no means 5 times as great as that by 1 ball, there can be, I think, no doubt that the strain produced by different weights of ball is in a ratio as high as that of the cube roots of the re-

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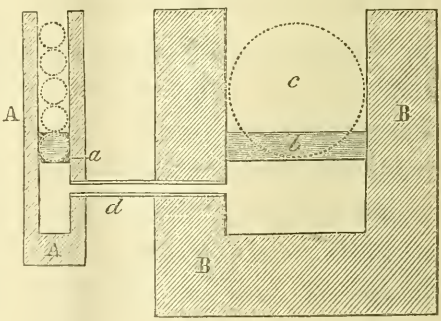

* The state of things here described will be comprehended by a glance at this figure. The two cylinders A and B, made in the proportions of 1 to 5, will resist an equal hydrostatic pressure, and the weights or plungers *a* and *b*, with which they are loaded, will remain supported upon the water in equilibrium, if an open communication be made between them by the pipe *d*. But if we load the larger one with

spective weights.* This would give, in the example before us, an increase of from 1 to 1.71, or the stress upon the walls of the 10-inch gun would be 71 per cent greater than upon those of the 2-inch gun.

The foregoing statement and comparison, however, do not present the whole case; for they are made upon the supposition that the charge of powder, in each instance, is as the square of the diameter of the shot, or that the cartridges of the 2 and the 10 inch guns are of the same length. This, if we take the charge of the small gun at $\frac{1}{3}$ of a pound, would give but $8\frac{1}{3}$ pounds for the large, or $\frac{1}{15}$ of the weight of the shot. The velocity obtained from this charge would produce neither range nor practical effect, and to obtain these results, that is, 1,600 feet a second, we must either increase the force through the whole length of the gun to 5 times that required for the small gun, or, the force remaining the same, we must provide

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the ball *c* instead of *b*, we shall require 5 balls, as shown in the small cylinder A, to balance the pressure of *c*.

* Hutton inferred that the velocities of balls of different weights with the same charges of powder, were inversely as the square roots of the weights, and Captain Mordecai, in his excellent book of experiments, makes the same inference. This would give no increase to the force of the powder, and must be impossible; and I find from comparing their experiments, and computing the forces developed by the same charges of powder with shot of different weights, that the forces are almost exactly as the cube roots of the shot. Thus Hutton's experiments with balls of 1.2 lb. and 2.9 lb., velocities 973 and 749, give forces almost exactly proportional to the cube roots of 1.2 and 2.9. Captain Mordecai's experiments with balls of 4.42 lb., 9.28 lb., and 21 lb., velocities 2,696, 2,150, and

for its acting through 5 times the space. Neither of these conditions can be practically accomplished. However, by an increase of both the charge and the length of the bore, the result may, in the limits under consideration, be attained. Thus, taking the large bore, if we double its length and make the cartridge 5 times as long, increasing the weight from $8\frac{1}{3}$ to $41\frac{2}{3}$ pounds, — or perhaps, having an advantage from the comparative diminution of windage and the better preservation of the heat, with a charge of from 30 to 35 pounds, — we may obtain the full velocity of 1,600 feet a second. But this again increases enormously the strain upon the gun.

It does not appear obvious, at a first view, how an increase in the charge should increase the tension of the fluid produced from it, if the cavity enclosing it be proportionably enlarged. If a steam-pipe a foot long will sustain the pressure of a given quantity of steam, of a given temperature, a pipe two feet long, of the same thickness and diameter, will sustain the pressure produced by a double weight of steam from the same boiler. Why then should the pressure upon a cannon be increased by a double length of cartridge? The difference seems to be this; with the steam, the press-

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1,520, all furnish, by computation, forces very nearly proportional to the cube roots of the respective weights of the balls. Every one knows that a small increase in the weight of the shot in a fowling-piece increases in a sensible degree the recoil, and the stress upon the gun. This is so universally received as true by ordnance officers, that it is a common practice to use two or more balls, instead of an increased charge, in proving guns.

ure is as in a closed cavity; with the powder, the tension depends upon the movement of the shot while the fluid is forming. Now, whether the charge be large or small, the motion of the shot commences while the pressure is the same in both cases, and before the charge is fully burned, and with the same velocity in both cases; but with the large charge the fluid is formed faster than with the small, while the enlargement of the cavity by the movement of the shot is nearly the same in both cases. This destroys the proportion between the sizes of the two cavities, and the tension must increase faster, and become greater, from the larger charge. The law of this increase cannot, from the complicate nature of the problem, be stated with any reliable exactness, but we may, I think, conclude, from the increased velocity of the shot, and many other effects, that the stress thrown upon the gun by different charges of powder, within ordinary limits, will not vary essentially from the square roots of those charges.* If then we increase, in the example

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* Hutton gives the velocities of the balls as the square roots of the charges, and the experiments of Captain Mordecai, although giving the velocities of the larger charges somewhat below this ratio, do not wholly contradict it. This assigns to the charges an effect, or power, that is, pressure multiplied by the space, which is directly as the charge. Now this result cannot be produced, with the larger charges, wholly by the continuance of the pressure during the last part of the passage of the ball through the bore, although a large portion of it may be derived from that source; but there must be a great increase of the tension in the fluid during the first part of the ball's motion, and an equal increase of the

under consideration, from a charge of $8\frac{1}{3}$ pounds to one of 32 pounds, the stress upon the gun, being as the square roots of these numbers, is raised from 2.88 to 5.65, or from 1 to 1.96. Having already increased the stress upon the gun, by the shot, from 1 to 1.71, if we multiply these together, we have a total increase of from 1 to 3.35. That is to say, if, under the conditions here stated, we load a gun of 2 inches' caliber with 1 shot and $\frac{1}{3}$ of a pound of powder, and a gun of 10 inches' caliber with 1 shot and 32 pounds of powder, the stress upon each square inch of the bores will be 3.35 times greater with the large than with the small gun; when at the same time, if the walls of both have a thickness proportional to the diameters of the calibers in each, the large gun will be incapable of sustaining a greater pressure per inch than the small one. Even with a charge of 12 pounds of powder, the stress upon the large gun must be more than double that upon the small gun when charged with one third the weight of its ball.

The preceding examination does not, I think, present the difficulties to be overcome in increasing the size of cannon as greater than they really are, and although the results that I have arrived at are from extreme cases, and may be said to be mere deductions, yet they are deductions legitimately drawn from the most reliable experiments that have been

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strain upon the gun. It appears to me that the hypothesis stated above, and the ratio of force there assigned to different charges, are in perfect accordance with these and other experiments.

made. How then can the necessary strength be obtained? Will it be answered, by an increased thickness? It is not necessary to examine the obvious objections of the great increase of size and weight that this implies, because no increase that can be given to the thickness will increase the strength to a sufficient degree to resist the force required. To prove this, I must ask attention to a further and somewhat elaborate examination.

About thirty years ago, Mr. Peter Barlow, of Woolwich, published a paper in the Transactions of the Society of Civil Engineers, on the hydrostatic press, in which he showed that hollow cylinders of the same materials do not increase in strength in the ratio of increase in thickness, but that the ratio of increase of strength is such, that, where they become of considerable thickness, the strength falls enormously below that given by the ratio of thickness. Mr. Barlow has carried out his reasoning in an analytical form, which I shall omit, while I endeavor to give the physical principles of the problem, as he has laid them down, in a form more clearly within the conception of all.* For this purpose let us suppose Fig. 1 to represent the cross-section of a hollow cylinder, like a cannon; A, the bore, 10 inches in diameter, B, the walls or body, 10 inches thick. Let this cylinder be distended by

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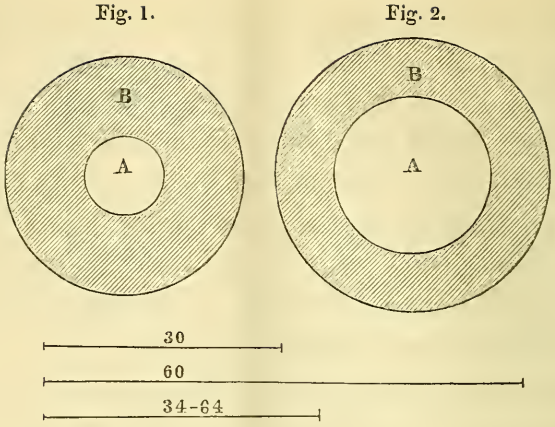
* Mr. Barlow's paper may be found in the first volume of the Transactions of the Society of Civil Engineers, and likewise in the Encyclopædia Metropolitana, and in the Treatise on the Manufactures of Great Britain, p. 326.



internal fluid pressure until the bore is 20 inches in diameter, as in Fig. 2. The external diameter will be increased only to 34.641 inches. For in Fig. 1 the whole diameter is 30 inches, and contains an area of $30^2 = 900$ circular inches. From this take the area of the bore $10^2 = 100$ inches, and we have 800 inches in the area of the solid walls. Now after it is distended, the area of the bore becomes $20^2 = 400$ circular inches, and as the walls contain the same area as before the distention, viz. 800, we have $800 + 400 = 1200$ circular inches for the area of the whole section, and $\sqrt{1200} = 34.641$ for the external diameter. Before the distention the circumference of the bore was $10 \times 3.141 = 31.41$, and the external circumference of the body was $30 \times 3.141 = 94.23$. After the distention the circumference of the bore is $20 \times 3.141 = 62.82$, and the circumference of the outside solid is $34.641 \times 3.141 = 108.81$. Every inch of the inner portion of the wall, then, by the distention has been doubled in length, while the external

circumference of the wall has been distended only in the ratio of 94.23 to 108.81, or from 1 to 1.155, less than one seventh part.

I have taken a case of extreme distention, for the purpose of showing more clearly the physical condition of the problem. But this makes the ratio of the differences less than they are when the distention is kept within the bounds of practice with iron cylinders. If, in the preceding case, the distention of the bore be made, what it may be in practice just before fracture, namely, $\frac{1}{1000}$th part of the diameter, we shall find that the external portion will be distended, practically, but one ninth part as much as the internal portion of the solid, and, if we take an infinitely small part for the distention, exactly one ninth. Now it is well known that with most bodies, including iron, within the strain of its elasticity the elongation is in exact proportion to the straining force. Hence with a cylinder such as I have described, if of cast-iron, the inner portion will be rent, or strained beyond its elastic power, at the instant that the outside portion is strained with only one ninth part of the load that it is capable of bearing. If the cylinder be made thicker than in my example, the load borne by the outside will be still less. If it be twice as thick as the diameter of the bore, the outside portion will be strained with only one twenty-fifth part of the load it is capable of bearing, when the inner portion is rent, and all the other parts must be rent in succession, without any increase of the load. The law of the diminution in the power of resistance may be stated as follows. Sup-

pose such a cylinder to be made up of a great number of thin rings or hoops, placed one within another. Then the resistance of these rings, compared one with another, to any distending force, will be inversely as the squares of their diameters.* With these incontrovertible laws of resistance before us, we cannot fail to perceive how impossible it must be to increase the strength of cast-iron cannon, in any useful degree, by an increase of their thickness beyond that now given to them.†

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* If we make a cylinder of 41 concentric hoops of equal thickness, disposed one within another, and exactly fitting, so that the particles of each hoop shall be in equilibrium with each other, the diameter of the largest being 5 times that of the smallest, then the force of each, beginning with the innermost, to resist distention, will be represented by the following numbers: —

1000	250	111	62
826	225	104	59
694	207	98	56
591	189	92	54
510	174	87	51
444	160	82	49
391	148	77	47
346	137	73	45
309	128	69	43
277	119	65	41
			40

An inspection of these numbers must, I think, impress any one with the fact, that it is impossible to increase essentially the strength of cannon, by a simple increase of thickness.

† I leave out of consideration another source of weakness, which comes from the unequal shrinking of the iron-casting. The heat from every casting is conducted away from the outside. Hence

Now, to obviate the great cause of weakness arising from the conditions before recited, and to obtain, as far as may be, the strength of wrought-iron instead of that of cast-iron, for cannon, I propose the following mode of construction. I propose to form a body for the gun, containing the caliber and breech as now formed of cast-iron, but with walls of only about half the thickness of the diameter of the bore. Upon this body I place rings or hoops of wrought-iron, in one, two, or more layers. Every hoop is formed with a screw or thread upon its inside, to fit to a corresponding screw or thread formed upon the body of the gun first, and afterwards upon each layer that is embraced by another layer. These hoops are made a little, say $\frac{1}{1000}$th part of their diameters, less upon their insides, than the parts that they enclose. They are then expanded by heat, and being turned on to their places, suffered to cool, when they shrink and compress, first the body of the gun, and, afterwards, each successive layer all that it encloses. This compression must be made such, that, when the gun is

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the outside *sets*, while the inside remains fluid. When the inside sets, the cooler solid shell that surrounds it contains more space than is required for the solid shrinking from the liquid state. This destroys the equilibrium amongst the particles, leaving them upon the *stretch*, or in a state exactly opposite to that in which, to give the greatest strength, they ought to be in, as we shall see hereafter. But the case, as I have shown it from other considerations, is so strong, or rather the gun is so weak, that I do not estimate this in this place, and only mention it in this note to show that I am aware of it, as all practical men must be.

subjected to the greatest force, the body of the gun and the several layers of rings will be distended to the fracturing point at the same time, and thus all take a portion of the strain up to its bearing capacity.

There may, at the first view, seem to be a great practical difficulty in making the hoops of the exact size required to produce the necessary compression. This would be true if the hoops were made of cast-iron, or any body which fractures when extended in the least degree beyond the limit of its elasticity. But wrought-iron and all malleable bodies are capable of being extended without fracture much beyond their power of elasticity. They may, therefore, be greatly elongated without being weakened. Hence we have only to form the hoops *small in excess*, and they will accommodate themselves under the strain without the least injury. It will be found best in practice, therefore, to make the difference between the diameters of the hoops and the parts which they surround, considerably more than $\frac{1}{1000}$th part of a diameter. The fixing the hoops in their places by the screw, or some equivalent, is absolutely necessary, not merely to reinforce the body against cross fracture, but to prevent them from starting with every shock of the recoil. I know, by experiment, that the screw-thread will fix them effectually. The trunnions must, of course, be welded upon one of the hoops, and this hoop must be *splined*, to prevent its turning by the recoil. Small *splines* should likewise be inserted under every hoop. It will, moreover, be advantageous to make the threads of the female

screws sensibly finer than those of the male, to draw, by the shrink, the inner rings together endwise.

It will be seen that, with a gun made in this way, we must depend upon the cast-iron body to resist the strain tending to produce cross fracture, though this resistance will be in some degree supported by the outer rings breaking joint over the inner rings. But if the body be made to constitute half the thickness of the walls, it will be found sufficient for the purpose without any reinforcement from the rings. This results from a principle or law, which, so far as I know, was first published by me in the year 1845, in a pamphlet on wrought-iron and steel cannon. As I cannot now put this matter in a better form than that in which I have there given it, I will here quote the statement as then made.

"Let us suppose that we have a hollow cylinder, say twelve inches long, the caliber being one inch in diameter, and the walls one inch thick, giving an external diameter of three inches. Suppose this cylinder to be perfectly and firmly closed, at its ends, by screw plugs, or any other sufficient means. Let this be filled with gunpowder and fired. The fluid will exert an equal pressure, in every direction, upon equal surfaces of the sides and ends of the hollow cylinder. Let us next examine the resisting power of a portion of this cylinder, say one inch long, situated in the middle, or equally distant from the ends, so that it shall not be strengthened by the iron which is beyond the action of the powder. The fluid enclosed by this ring of one inch long contains an area

of one square inch, if a section be made through it in the direction of its axis; and the section of the ring itself, made in the same direction, will measure two square inches. We have then the tenacity or cohesive force of two square inches of iron in opposition to an area of the fluid measuring one square inch; and if we take the tenacity of the iron at 65,000 pounds, the cylinder will not be burst, in the direction of its length, unless the expansive force of the fluid exceed 130,000 pounds to each inch. Next, let us suppose a section made through the cylinder and fluid, transversely. The area of the fluid, equal to the square of the diameter of the hollow cylinder, is one circular inch, and the area of the whole section, the diameter being three inches, is nine inches. Deduct from this the area of the caliber, and we have eight circular inches. That is, the section of the iron is eight times greater than that of the fluid; whereas in the former case, of longitudinal section, the iron gave but twice as much surface as the fluid; and if we take, as before, the iron at 65,000 pounds per inch cohesive force, it will not be broken unless the force of the fluid exceed 520,000 pounds. It will be found, upon a further examination, that the relations of these sections to each other may be varied, as we take the diameter of the caliber to be greater or less, as compared with the thickness of the sides, but their difference can never be made less than as two to one. Here then is a principle, or rather a fact, of the utmost importance in forming cannon of any material, the strength of which is different in different direc-

tions; for as a cannon made in the proportions above specified, if the materials be in all directions of equal strength, will possess four times as much power to resist a cross fracture as it does to resist a longitudinal fracture, it follows, that a fibrous material which possesses four times the strength in one direction that it does in another, will form a cannon of equal strength, if the fibres be directed round the axis of the caliber. It is this fact which gives the great superiority to the various kinds of twist gun-barrels. For in these, although the fibres do not enclose the caliber in circles, yet they pass around it in spirals, thus giving their resisting force a diagonal direction, which is vastly superior to the longitudinal direction in which the fibres are arranged in a common musket-barrel."

The foregoing example supposes the cavity immovably closed at its ends, and gives to the powder more force than it actually exerts, in gun-practice, to produce cross fracture, compared with its force to produce lengthwise fracture, even at the part nearest to the breech of the gun; and as the recoil is resisted by the whole gun, the stress upon any part will diminish as the inertia, or weight, diminishes from the breech to the muzzle.

With these facts, principles, and laws, thus stated, I proceed to give some calculations to show the strength of a cannon constructed in the way that I have pointed out, as compared with one made in the usual manner. Take a cannon of 14 inches' caliber, which will carry a spherical solid ball of 374 pounds, with sides 14 inches thick, made up of 7 inches of

cast-iron, and two hoops or rings, $3\frac{1}{2}$ inches each, of wrought-iron. The external layer of cast-iron will, from its position, as before explained, possess but one fourth of the strength of the inner layer, or whole strength of the iron, and the mean strength of the whole will be reduced one half. Take cast-iron at 30,000 pounds to the inch area, and we have $30{,}000 \times \frac{1}{2} = 15{,}000$ pounds to the inch. The thickness, of both sides, is 14 inches, and $15{,}000 \times 14 = 210{,}000$ pounds for the strength of the casting, to each inch of its length. The first hoop has its strength reduced from 1 to a mean of .8. Take the strength of wrought-iron at 60,000 pounds to the inch, and we have $60{,}000 \times .8 = 48{,}000$ pounds to the inch. The thickness, of both sides, is 7 inches, and $48{,}000 \times 7 = 336{,}000$ pounds. The outside ring must be reduced in strength by the same rule, for its mean, from 1 to .832, which gives it 49,920 pounds per inch, and for the 7 inches 349,440 pounds. We have then, for each inch in length,

Cast-iron body of the gun	210,000 pounds.
Inner wrought-iron hoop	336,000 "
Outer wrought-iron hoop	349,440 "
	895,440 pounds.

The diameter of the bore being 14 inches, we have $\frac{895440}{14} = 63{,}960$ pounds, as the resistance to oppose to each square inch of the fluid from the powder. The gun will bear, then, a pressure of 4,264 atmospheres.

The resistance to cross fracture at the part nearest to the breech will be, from the cast-iron, $28^2 - 14^2 = 784 - 196$ circular inches, equal to 460 square inches.

Cohesive force, unreduced, 30,000 pounds, and 30,000 $\times 460 = 13{,}800{,}000$ pounds, the whole strength. The bore contains 153 square inches, and $\frac{13800000}{153} =$ 90,196 pounds to resist each square inch of the fluid, or 26,236 pounds to each square inch more than is provided to resist the longitudinal fracture; and this excess will be further reinforced by the wrought-iron rings, which, being screwed upon the casting, and the outer layer breaking joint over the inner, will add to the resistance to a great amount, which however need not be computed.

Let us now examine a gun made of a single casting of the dimensions that are given above; that is, of 14 inches' bore, and sides 14 inches thick. Taking the normal strength of cast-iron as before at 30,000 pounds per inch, we must reduce it, according to the laws before explained, to one third, or a mean of 10,000 pounds per inch; and the thickness of both sides being 28 inches, we have $10{,}000 \times 28 = 280{,}000$ pounds for the whole strength, and $\frac{280000}{14} = 20{,}000$ pounds to each inch of the fluid pressure, or 1,333 atmospheres, or $\frac{20000}{63960}$, or less than one third of the first example. Against a cross fracture the cast gun will possess a great excess of strength, which I do not like to call useless, although I do not perceive how it can be of any essential, practical advantage.

Let us next inquire, What force is required to give a ball of 14 inches' diameter a velocity of 1,600 feet a second? We shall obtain a better conception of this force by estimating it in the height required by a fluid column to produce it. Suppose the ball im-

pelled by the pressure of a column of the same substance, which would be in this case a column of fluid iron. Then (from the formula $v = \sqrt{2gh}$) we obtain $\frac{1600^2}{64} = \frac{2560000}{64} = 40{,}000$ feet, for the height of the column. But this would produce a jet forming a continuous stream. Suppose this stream to be 14 inches in diameter, and divided into a series of short cylinders, each of which, to equal a ball of 14 inches' diameter, must be $9\frac{1}{3}$ inches long. Now in giving 1,600 feet velocity to this series of cylinders by a superincumbent column, the force will act upon each cylinder only through a space equal to its length. But in a cannon the powder acts, though with a variable force, through the whole bore of the gun. The variation of this force must depend, in every case, upon the quickness of the powder, arising from its composition, fineness of grain, dryness, and the heat received from the gun from previous firings; and most essentially from the amount of the charge; and we do not know the exact law of the variation for any one case or condition. Our best judgment, therefore, must be but an approximation to the truth, entirely empirical. But if we cannot determine the truth with exactness, we can at least assign limits within which it must be contained, and upon a comparison of the velocities produced by different lengths of bore, the effect upon the gun itself at different parts of its length, and various other grounds of comparison, I think that we may take the effect of the charge through the whole bore, supposing it to be 112 inches from the ball to the muzzle, and the charge

80 pounds, as equal to the action of the maximum force through a space of not less than one half, nor more than two thirds, of its length. But that I may be sure to assign the maximum so great as to cover all anomalous or accidental conditions, I will take it as sufficient to produce a velocity of 1,600 feet a second, if acting constantly through one third the length of the bore. This will give $37\frac{1}{3}$ inches, or exactly 4 times the length of the cylinder which forms the equivalent of the shot. Then (from the formula $v = \sqrt{fs}$) the 40,000 feet above given for the height of the column, becomes $\frac{40000}{4} = 10{,}000$ feet; * and if we take the whole force of the powder as equal to its maximum force, acting through two thirds the length of the bore, or $74\frac{2}{3}$ inches, our column will become 5,000 feet high. In all cases of providing strength, we must take the force to be resisted at its maximum.

Now a bar of cast-iron 1 inch square weighs 3.2 pounds to the foot in length; we have then $10{,}000 \times 3.2 = 32{,}000$ pounds' pressure to each square inch of surface, or $\frac{32000}{15} = 2{,}133$ atmospheres, on the supposition that the whole action of the powder is equal to its maximum force through one third the bore of the gun. If we take the whole action as equal to its maximum through two thirds of the bore, the column,

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* This whole matter may be taken from the formula $\frac{v^2}{2gs} = f$, which gives the force 12,860 times gravitation. But I have preferred to give the more circuitous course, from the pressure of a column, as fixing a better conception of its enormous amount upon the mind.

5,000 feet high, gives 16,000 pounds, or 1,066 atmospheres. It cannot be less than this, and although it may never come up to the greater number, or 2,133 atmospheres, it would not be safe to estimate it at less when providing the means to resist it. We require, then, a pressure of 32,000 pounds to the inch, to obtain for a 14-inch shot an initial velocity of 1,600 feet a second. We have seen that a gun formed as I have proposed will be capable of resisting a pressure of 63,960 pounds to the inch, or very nearly twice the pressure required to produce the velocity sought, while with a gun made in the usual way, of one piece of cast-iron, the power of resistance is limited to 20,000 pounds to the inch, or less than two thirds that which may be required to obtain the velocity.

We have seen that a cannon constructed in the manner recommended, of whatever size, having its walls equal in thickness to the diameter of its bore, will sustain a pressure of 63,960 pounds, equal to a column of fluid iron 20,000 feet high, very nearly. This is half the strength required to support a column capable of keeping up a continued stream with a velocity of 1,600 feet a second. Suppose that we construct such a cannon with a bore of 30 inches, and of such length that the ball shall receive the force of the powder while it moves through a space of 10 feet, and that this force be equal to a constant action of 4,266 atmospheres through 40 inches. It will be at once perceived that it will impress the above velocity upon a cylinder $\frac{40}{2} = 20$ inches long, or upon its equivalent, a sphere 30 inches in diameter. Such

a sphere of solid iron will weigh 3,670 pounds, and at this point the *calculated* power of the gun meets the force required to give a velocity of 1,600 feet a second.

Although this size may be beyond practical reach, the contemplation of it as a theoretical perfection may stimulate us to attempt an approximation to it. A ball of a ton weight, with a range of, say 6 miles, would, as a mere display of mechanical force, be worthy of a great effort.

The following columns show the stress that the several kinds of guns, as mentioned, will bear, by calculation, and the pressure required to give the velocity of 1,600 feet a second. The third column shows the proportion between the required and the actual strength.

	Atmospheres.		Atmospheres.	
Hooped cannon for 14-inch shot will bear	4,266 ;	required	2,133	100 : 200
Cast-iron gun, 14-inch shot, will bear	1,333 ;	"	2,133	100 : 62
Cast-iron 32-pounder cannon, 6¼ inches thick, will bear	1,333 ;	"	920	100 : 142
Hooped cannon 30 in. diam. 3,670 lb. shot,	4,266 ;	"	4,266	100 : 100

By this it appears that a common cast-iron 32-pounder, having but 42 per cent more strength than is required, is less reliable than a hooped gun of 14 inches. It will be recollected that the numbers given above in the second column, as showing the required strength, represent the utmost force ever exerted by a charge intended to produce a velocity of 1,600 feet a second.

In this paper, my principal object has been to show a mode of construction by which, with our present materials and knowledge, it will be per-

fectly practicable to make guns of great size capable of standing the requirements of the service. It follows almost of course, that the same form of construction must be the best possible for guns of smaller caliber, and that by adopting it, not only will the use of guns of enormous size be rendered practicable, but, if applied to cannon of smaller size, their bursting will be rendered almost impossible. If it be necessary to use the word *cost* in connection with the object to be attained, I *know* that when the manufacture is mastered, with a good machine-shop, the difference between the last of these and common cast-iron guns will be altogether insignificant to the nation.

I abstain from opening the subject of different forms of bore and of shot, although I believe that in the end some cylindrico-conical form, lightened with cavities in the rear portion, and perhaps with some form of spiral grooves to produce rotation from the air, will be substituted for the solid spheres now used.

I shall likewise forbear all description of apparatus for restraining recoil, by friction, although it will be necessary to resort to such means for the full development of the advantages of the form of cannon herein pointed out.

I should, however, leave the subject of this paper but very imperfectly treated, if I neglected to mention one most important effect of the force of the explosion, which is not indicated *a priori* by any theory, and which is so inconstant and uncertain in amount,

that it can be appreciated only by a careful observation of its practical effects upon the gun, but which, unless guarded against, must essentially disturb the conclusions which I have herein deduced. I allude to what is known to artillerists as the lodgment or indentation of the ball. This first shows itself at the point immediately under the ball, where it rests at the moment of the discharge. It is best observed in a soft bronze or wrought-iron gun, and from the first instant of its appearance, as a slight impression of the under surface of the ball, it goes on increasing at every discharge, until it becomes so deep as to deflect the ball upwards at the instant of its flight, to strike the upper surface of the bore, where a second indentation is made, considerably in advance of the first, and from this a third, still more advanced, upon the under side. These indentations go on increasing in number and size, and at length bulges appear upon the outside of the gun, which becomes oval near the muzzle, and is at last destroyed.

The lodgment here described has been attributed wholly to the downward pressure of the fluid when escaping through the opening of the windage, which is all upon the upper side of the ball, the under side resting by its weight in contact with the bore. There must undoubtedly be a great escape, not only of the fluid, but of burning powder in grains, through this passage, and the downward pressure from these causes may present an excess over the opposite pressure of the powder upon the under side of the ball, capable of producing some impression upon the under

surface of the bore. I am inclined, however, to attribute the indentation mostly, if not entirely, to the compression of the back hemisphere of the ball under the enormous blow of the explosion, producing a corresponding enlargement of the ball in its diameter transverse to the axis of the bore. The smith produces such a change of form in his bar of iron, at pleasure, by the blows of a sledge applied to its end. The operation is called *upsetting*. This enlargement must impress itself upon the part of the bore upon the under side upon which the shot rests, and is alone sufficient, in my mind, to account for the whole mischief.

This view of the subject is confirmed by the form of the lodgment, which consists, at first, of a single narrow impression, exactly corresponding to a very small segment of the ball, and not in the least in advance of the spot on which the ball rests before the discharge. Now this would be the exact form and place of an impression produced by a sudden enlargement of the ball, and an equally rapid recovery of its true figure, which it would derive from its elasticity. But if the lodgment were produced by the pressure of the fluid upon its upper surface, it ought to form a long groove or channel, ceasing only with the diminished pressure of the fluid near the muzzle. Furthermore, the lodgment is greatest when a hard oakum wad is used behind the ball. Now such a wad must prevent, in some degree at least, the escape of the fluid, and therefore diminish the downward pressure. But such a wad, driven hardest

against the middle of the ball, in its rear, would act most advantageously to produce the lateral enlargement by *upsetting* it as before described.

Hard cast-iron guns do not exhibit this indentation in so great a degree, because, being unmalleable, they are incapable of a permanent change of form without fracture. With them, therefore, this pounding of the ball, being repeated a few hundred times, shatters the walls of the gun, which at length gives way at once and goes to pieces.

It must be obvious, that, if the lodgment be attributed to either or both of the causes which I have recited, it may be prevented by a most simple and easy means. This is nothing more than providing that the ball shall, at the moment of the explosion of the powder, have no part in contact with the bore of the gun, but that the windage space shall be equally distributed about the whole circumference. This may be entirely secured by enveloping the ball in a bag made of felt, or of hard woollen cloth, having an additional patch upon its under side to compensate for the weight of the ball. It would seem impossible that in this condition the ball, receiving the pressure of the powder equally distributed in the direction of the axis of the caliber, should touch the gun more than by a slight graze during its flight.*

* My observations upon the lodgment have been made upon wrought-iron cannon. Between the years 1841 and 1845, I made upwards of twenty cannon of this material. They were all made up of rings, or short hollow cylinders, welded together endwise. Each ring was made of bars wound upon an arbor spirally, like

Unless this or some equally efficient remedy is adopted, any considerable increase in the size of cannon must be hopeless; for a surface as hard as a smith's anvil would give way under the long-continued pounding of naked twelve-inch shot; and when-

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winding a ribbon upon a block, and, being welded and shaped in dies, were joined endwise, when in the furnace and at a welding heat, and afterwards pressed together in a mould by a hydrostatic press of 1,000 tons' force. Finding in the early stage of the manufacture that the softness of the wrought iron was a serious defect, I formed those made afterwards with a lining of steel, the wrought-iron bars being wound upon a previously formed steel ring. Eight of these guns were 6-pounders of the common United States bronze pattern, and eleven were 32-pounders of about 80 inches' length of bore, and 1,800 pounds' weight. Six of the 6-pounders, and four of the 32-pounders, were made for the United States. They have all been subjected to the most severe tests. One of the 6-pounders has borne 1,560 discharges, beginning with service charges and ending with 10 charges of 6 pounds of powder and 7 shot, without essential injury. It required to destroy one of the 32-pounders a succession of charges ending with 14 pounds of powder and 5 shot, although the weight of the gun was but 60 times the weight of the proper shot. If any of these guns are ever destroyed by firing them, the destruction will commence in the lodgment.

It was during a course of experimental firing with the soft wrought-iron gun, that I had an opportunity of observing the formation and increase of the lodgment; and here I was led to the experiment of placing the shot in a bag, as recommended in the text. My experiments were not sufficiently extended and varied to lead me to an assured conviction that the evil may be entirely prevented by this practice; but they were enough to lead me to a confident expectation of that result, as I could never detect the formation of any lodgment or any increase in one previously formed when the bag was used.

I cannot leave this subject without observing that I regard the

ever hooped cannon may be made and used, it will be essential that the means of preventing the lodgment herein given be always and at all times carefully applied.

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late, and still continued, attempts to make wrought-iron cannon in Europe by the process of *fagoting* or *piling*, as a strange engineering delusion. It may not surprise us that *amateur* engineers, whose whole knowledge of the character of iron is derived from a printed page, should expect useful results from this attempt. But that men practically acquainted with working iron should expect to forge a serviceable gun of wrought-iron by the same process that is used to produce a shaft of that material, seems to me not very creditable to the *iron* knowledge of the age.

RIFLED CANNON.

Cambridge, April 7th, 1860.

Hon. John B. Floyd, *Secretary of War:* —

Sir, — At the close of the interview with which you favored me, lately, in Washington, you requested me to recapitulate, in the form of a letter, the statements I had made to you concerning improvements in cannon, especially *rifled cannon,* with such additional observations upon the subject as might occur to me. You desired me to do this to enable you to give the matter a more deliberate examination, and that it might remain for reference hereafter upon the files of your office.

Before entering further upon the subject, permit me to remind you of the two papers, copies of which, in pamphlet form, were forwarded to you the day after our interview, and to hope that you have been able, notwithstanding the great and pressing calls upon your time by your official duties, to go over the principal facts and deductions contained in them. The first of these pamphlets, entitled "A Short Account of an Improved Cannon," published in 1845, was, mostly, republished by the Committee on Naval

Affairs, in 1846 (see House Doc. No. 681, 29th Congress, 1st Session), its principles adopted, and recommended as a basis for the future arming of the war steamers of the United States. It was likewise translated, at the School of Artillery at Vincennes, into French, in 1848, and circulated in that language through Europe. The second pamphlet, published in 1856, contains an account of my further investigations in the same subject, and gives, as I believe, an improvement upon the mode of construction first proposed. In both the forms of construction therein recommended, however, the object proposed was *strength* and *endurance*, and thereby a power of greatly increasing the caliber of the gun, and consequently the size of the shot, without altering its shape or figure from that which up to that time had alone been used, namely, a globe, and that without giving it the rotation of the rifle-ball. In this letter, it is my purpose to show that the late application of the rifled bore to cannon will be most rapidly and certainly developed and reduced to practice by adopting one of the forms of construction devised by me, and described in the papers before referred to; and that whatever experiments may be made with cast-iron and bronze, or by *fagotting* masses of wrought-iron, they must end in the principle of construction already demonstrated by me as giving greater strength and endurance than any other.

The extension of the well-known principle of the rifle, to cannon, which has been but very recently practically accomplished, is without doubt destined to work a vast improvement, and extend enormously

the destructive power of this great instrument of war. But rifled cannon are yet in their infancy; for although great precision of direction is obtained by the rotation of the missile, and great range of flight by its elongation, yet this very elongation of the shot, by increasing its inertia, throws such stress upon the walls of the gun, that its application hitherto has been found impracticable to guns of large caliber, if they be made of the common materials, cast-iron and bronze, and in the usual way; and I take it now to be a conceded fact, that cast-iron and bronze can only be used for rifled cannon of very small caliber, and with hollow shot, or with small charges of powder. So that, although a very long range is obtained from avoiding or evading the resistance of the atmosphere by the elongation of the missile, yet it is impossible, by these guns, to combine weight of shot with high initial velocity; and for the importance of the latter, as an element of efficiency, I beg leave to refer to an able article in the American Journal, by Major Barnard of the U. S. Engineers.

Such being the state of things, the English government have adopted a plan proposed by Mr. (now Sir William) Armstrong, of a breech-loading rifled cannon, and they have prepared works upon a most extensive scale and at a vast cost to manufacture it. This gun is made of wrought-iron, and for its mode of manufacture, in principle and detail, in every particular, the rifling and breech-loading of course excepted, the Armstrong gun is a close imitation, or I will not say but, possibly, a reinvention of the

method devised and carried into practice by me between 1840 and 1845, and by which I made ten guns for the United States government, which they now possess, some of them thirty-two pounders, 6.4 inches in caliber, which is very much larger than any gun yet made upon the plan by Armstrong. My improvement was patented and a minute specification enrolled in England in 1845, and the pamphlet published in 1845 sent, in 1848, to the principal officers of the army and engineers there. Any one who will read my specification and compare it with the last account of Armstrong's method, as published in the Times newspaper, must see that in the principle of winding and welding and *forming the rings in a mould*, the methods are identical. He indeed uses a steam hammer instead of an hydraulic press, as used by me, and which is, as I hold, the better power. There is, however, in his method necessarily an imperfection, in the last uniting of the *rings*, that is avoided in my guns; and I may mention, moreover, that my guns had the advantage of a steel lining.

Although the breech-loading apparatus attached to Armstrong's gun may prove too complicate and delicate for the rough usage to which it will be exposed, there can be no doubt but a gun constructed in this way, and used as a muzzle loader, is superior in strength to any of the cast-iron, bronze, or fagotted wrought-iron guns that have preceded it; and through it and the use of elongated shot the advantages of rifled cannon have been fully proved and set at rest.

But is this the best form or mode of construction possible for a rifled cannon? Now, that must be the best gun, whether rifled or smooth bore, which combines the greatest degree of *strength* with *endurance*, and the experiments made by the United States ordnance officers, and which are partly recorded in the pamphlet of 1845, show a strength and endurance in the guns made by me upon the plan since followed by Armstrong, never equalled before or since. At the same time, when I have taken into consideration the cost of those guns, the great attention, and, if I may be permitted to use the word, skill, required in their manufacture, I have come to the conclusion that a modification of that form of construction may be made, in which most of its essential advantages, with some of another character, may be obtained with a great saving of machinery, labor, and cost.

This modification is detailed at sufficient length in the memoir of 1855, republished in 1856 in pamphlet form, p. 19 *et seq.* Now it appears from what is demonstrated in that memoir, and given in the table, p. 29, that a cannon constructed as therein described will possess more than *three times the strength* of a common gun of like weight and calibre. Does not this indicate, unmistakably, the course that must be taken to produce the most efficient rifled cannon? By adopting it, not only will the size of the missile be increased over anything yet effected by any foreign engineer, but the old initial velocity of the cannon-shot restored; thus greatly increasing its range and precision, and reducing the curve of the

trajectory to almost a straight line, thus bringing any object that can be seen within the point-blank range. Not only are the facts and principles on which these results are predicated demonstrated in the memoir above cited, but the strength of this construction has been already proved in Europe, where a hooped cannon was constructed by Captain Blakely, a very ingenious and scientific officer of Royal Artillery, in 1857, and tried in December of that year, which gave results entirely decisive of its claim to superiority.

That I may do no injustice to others while asserting my own claims, I will state that Captain Blakely's investigations were no doubt original and independent of mine, as he commenced them before anything upon this particular form of gun was published by me in Europe. In addition to what is above stated, I am informed that the French are at work upon it, and that the Spanish rifled cannon used in the late battles in Morocco were formed upon this plan.*

Under these circumstances may I not say, that it seems to me strange that this country, which stands so high and is so progressive in all that relates to material development, should neglect this improvement in a most important instrument of defence,

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* Since writing the above, I have learned that the Whitworth cannon, which has lately excited much attention in Europe, is formed upon the same model of strength. In the accounts of it published by Mr. Whitworth this fact is not mentioned, but he describes it simply as made of *homogeneous* (*qu.?*) iron.

although it is a native of the soil, while it is receiving attention and favor in Europe generally? *

Trusting that the details of this letter have not exhausted your patience,

I have the honor to be

Your obedient servant,

DANIEL TREADWELL.

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* See "Scoffern on Projectile Weapons of War," p. 266 (London, Longman & Co.), and "Navies of the World," by Hans Busk, p. 268.

ON THE

CONSTRUCTION OF IMPROVED

ORDNANCE,

AS PROPOSED IN A LETTER TO THE

SECRETARIES OF WAR, AND OF THE NAVY, AND THE CHIEFS OF THE BUREAUS OF ENGINEERS, AND OF ORDNANCE, OF THE UNITED STATES.

BY

DANIEL TREADWELL,

LATE RUMFORD PROFESSOR IN HARVARD COLLEGE.

CAMBRIDGE:
WELCH, BIGELOW, AND COMPANY,
PRINTERS TO THE UNIVERSITY.
1862.

ADVERTISEMENT.

THE following letter was forwarded to the five officers of the United States Government to whom it is addressed, on the day of its date. It was sent in a printed form for their more ready perusal. As no notice whatever has been taken of it, the writer now lays it before the public, and especially before the members of the Congress of the United States. He has endeavored to state in the briefest possible form all that relates to himself, personally; and he now asks attention to the subject only in so far as it derives importance in relation to the *National Defences*, and as an investigation in a subject of practical science.

CAMBRIDGE, January 28th, 1862.

Cambridge, Dec. 23, 1861.

To Hon. SIMON CAMERON,
Secretary of War,
Hon. GIDEON WELLES,
Secretary of the Navy,
Gen. JOSEPH G. TOTTEN,
Chief of the Bureau of Engineers,
Col. JAMES W. RIPLEY,
Chief of the Bureau of War Ordnance,
Capt. A. A. HARWOOD,
Chief of the Bureau of Navy Ordnance.

Gentlemen: —

In the year 1840, I determined to attempt the construction of cannon of wrought-iron, following certain theoretical principles which I had long held under consideration. I then had under my control a small forge and machine-shop, and several skilled workmen. I commenced upon three and four pounder guns, of which I made three, and subjected them to such proofs as satisfied me that the principle upon which I wrought was true, and that it might be carried into successful practice, beyond a mere experiment. To do this, however, required engines and tools of an elaborate and costly kind, and some assurance that the guns produced would be adopted by the government. To obtain this assurance, I went

to Washington, and after interviews with the Secretaries of War and the Navy, Messrs. Spencer and Upshur, and the ordnance departments under their control, I obtained a contract, from the former, for six or eight 6-pounder field guns, and from the latter for four light 32-pounders. Returning then to Boston, I commenced erecting a building with furnaces and tools for the proposed manufacture. All this involved a large outlay of money, and the devotion of some part of every day for nearly three years. It was not, therefore, until the year 1843 that my first contract for the six-pounder army guns was completed. But these guns being finished and proved to the entire satisfction of the then very able Chief of Ordnance, Colonel Talcott, I commenced upon the larger navy guns. A full year was taken up with this and some six or eight others of the same caliber, made on my own account. These likewise endured not only the contract tests, but those of a much more severe character to which I determined to subject them. A short account of the manufacture of these guns was published by me in 1845, and circulated both here and in Europe. I need not enumerate the steps by which the foregoing work was accomplished, nor the particulars of expenditure connected with it. I will only say that the outlay of my own money, and that of a few gentlemen pecuniarily connected with me, was more than seventy thousand dollars, and that over sixty thousand remains unreturned.

Although I had thus produced stronger and better guns than had ever before been made by man, I failed to obtain that government adoption without which it was impossible for me to go on. The War Ordnance Board indeed offered to order a few batteries of field guns. But my chief reliance had always been upon the Navy. To substitute these light guns, though of great caliber and power, for the old and ponderous cast-iron guns, would, I thought, be an advantage so evident that it must be taken into favor. In this I was mistaken; and although my cannon was a complete success in all that related to its construction, it was an utter failure as regards its adoption by the government. That it was successful as a construction, I have only to say that Sir W. Armstrong, twelve years after I was obliged to abandon it, and after learning, as I fully believe, the method by which I produced it, formed his rifle cannon upon the same plan,* and I defy him now, with the whole patronage

* When I first read an account of the method followed by Armstrong in constructing his gun, although I saw at once the exact resemblance of it to the method invented by me in 1840 – 44, yet not being aware of the fact that the specification of my English patent had been published *in extenso*, I thought it might be that Armstrong had re-invented my form of gun and the machinery required to produce it. But since writing this letter I have looked into that great work, "The English Printed Specifications," a copy of which is in the Boston Library; and I there find, that the specification of my English patent, enrolled July 5th, 1844, No. 10,013, was printed in 1854. This patent was taken out in the name of Thomas Aspinwall, then American Consul at London, who acted as

of the British government, to produce a more perfect gun, so far as *strength*, *soundness*, and *finish* are concerned, than I produced seventeen years ago by private means alone. I limit my boast to the above enumerated particulars, for as to Armstrong's inventions in rifling and breech-loading, he deserves in my opinion much credit for them, and I hope that I shall be the last man to deny to another all that belongs to him. Although I was thus obliged to suffer the loss and shame of defeat, and to abandon all that I had done, the mechanical theories upon which I had wrought, and developed in practice, had made a strong lodgement in my mind. I had early seen that the

my attorney. The specification was written by me, and transmitted, complete, to him. It occupies twenty-one large printed pages, with full references to elaborate drawings, which occupy a large folio plate, of the machinery used by me in constructing the cannon. Any one acquainted with what Armstrong calls his gun, and the mode of constructing it, will find here everything relating to it so far as its structure, *without rifling and breech-loading apparatus*, is concerned. There is no difference whatever in the form of the construction, the mode of putting the rings together within the furnace, or the tools and enginery required for the work, except the substitution by Armstrong of a steam hammer for the hydrostatic press used by me.

Now, Armstrong has shown, by his denunciation of patents, to the British Association, that he is well read in the record of them, is it then probable that this has been overlooked by him? And will the high-minded and honorable men, the English engineers, especially those who constitute the Institution of Civil Engineers, suffer this plagiarism, or piracy, taking whichever of these ugly words may best describe the act, to pass unchallenged in England?

principal objection made to adopting my cannon lay in its price, and in the skill and attention that must always be required in its manufacture. To obviate these I proposed to myself to form a cannon of a thin cast-iron body surrounded by several layers of wrought-iron or steel hoops, placed upon it under *great strain.* I determined, by calculation, that this would be nearly, perhaps quite, as strong as my abandoned form, would come within the reach of ordinary skill, and would be in the long run cheaper than the ordinary cast-iron gun.

Thwarted as I had been by most of the government officials and government boards, I had no heart to move in this matter practically at any great expense. Indeed, I had not the means to permit me to do it, and I had already led others to spend more, from their confidence in my representations, than I chose to do again. No other course seemed open to me but to secure the invention by patent, publish an account of it with an exposition of its principles, ask the government to adopt it, and wait the event. Early in the year 1855 I determined to adopt this course, and in June of that year I completed my specification and drawings for a patent. In September I commenced writing an account of its structure and a demonstration of its strength. This account, although finished in November, was not, owing to several unforeseen hindrances, published until the beginning of 1856. As soon as it was printed, I sent copies of it to all

the military and naval posts and stations, and especially to the ordnance officers at Washington. I likewise wrote a letter to the chief of the Ordnance Bureau, calling his attention to it, stating, amongst other things, that it must soon come up and be adopted in Europe, — that it must be taken up here in the end; — why not, then, commence now, and have the credit, if any credit should come of it, of leading the way in it, rather than be driven by others to the use of it? To this letter no answer or acknowledgment was ever returned.

Again, two years after this, the rifled cannon made its appearance in England. To carry this out, Armstrong, as I have said before, constructed his gun after the method used by me eighteen years before. It now seemed to me that it would give us a great superiority over all the European forms of rifled cannon to apply the principle of the rifle-ball to cannon constructed after the method last proposed by me. So strongly was I impressed with this idea, that in February, 1860, notwithstanding my age and feeble health, I made the journey to Washington to urge it upon the authorities. I found them all as torpid as to any of the improvements of Europe, in rifled cannon, as they were to improvements in naval matters in the Sandwich Islands. I obtained, after a long and *im*-patient waiting, an interview with the Secretary of War, Floyd. He treated me courteously, though I saw at once, that he knew nothing, and

cared nothing, about rifled cannon. But as he requested me, on taking my leave, to put the substance of the statement which I had made to him in writing, I did so, on my return home, and forwarded it to him. This completed my intercourse with him, though I afterwards printed my letter, a copy of which is herewith enclosed.

Here the matter has rested so far as applications from me are concerned. In the mean time the country has become involved in a great and trying contest, without any adequate provision of guns, either in number, or kind, such as the contest requires. Being about to move in again urging the propriety of adopting the gun which I have so many times heretofore proposed for adoption, I have been informed that all other plans of large cannon, at least, are to be given up, in favor of a gun brought out by Captain Rodman of the Ordnance. A detailed account of this gun is contained in a series of Reports made by Captain Rodman, of his experiments, performed, through a number of years, and at a very great expense to the government, and now printed in a very costly form, but not published, in the usual sense of that word. The experiments had for their ultimate object the improvement of cast-iron ordnance, and more especially to prove the value of a method, devised by Captain Rodman, of cooling the gun from its fluid state. To accomplish this, he restores the old method of casting the gun upon a

core, and passes through the axis of this core a stream of cold water. The purpose of this is to produce a more perfect equilibrium of the particles of iron than they possess when the cooling is performed from the outside surface, as is the case when guns are cast solid. This seems to be a good method for casting large guns, and the few experiments that have been made upon proving, to extremity, guns cast in this way show in its favor. He produces, after all, but a cast-iron gun, and the labors of others, upon other materials, have established the fact that cast-iron guns and round shot are soon to give place to another generation, formed of a different material and upon an entirely different plan. But of this I shall speak hereafter.

The first question now is, whether Captain Rodmon's experiments, and the deductions drawn from them, are trustworthy. Now, the whole superstructure which he lays out, and proposes to raise, depends upon an instrument which he has constructed for determining, as he supposes, the actual force of the fluid produced by fired gunpowder under almost all possible circumstances, and the power of cast-iron guns to resist the force thus created without being destroyed by it. This instrument is at once the compass, quadrant, and chronometer by which he is guided in his voyage of discovery. It is described particularly at pages 174 and 175, with a good plate annexed. Plates of it are given likewise in some

modified form, in several other places. In speaking of it here, therefore, I shall suppose that the reader has Captain Rodman's book before him, open at page 174, and that he understands the structure and working of the instrument, as there set forth.* Let us, then, see whether the instrument will perform what is claimed for it. First, then, it is said that the indentation or impression made by the blunt or diamond-shaped point indicates the *pressure* of the fired gunpowder; that it acts by *pressure* purely, as a heavy weight acts when placed slowly upon a support, and not by a blow, as the same weight will act when suffered to fall through some sensible space, and certain facts are adduced at page 178, to sustain this view. I shall not stop here to show the fallacies

* This instrument and its use will be understood by any engineer or intelligent mechanic from the following description. Suppose a row of six small holes to be drilled through the side of a cannon, into its caliber. These holes are placed 14 inches apart, and, commencing near the breech, extend to near the muzzle, or a distance of 84 inches. The instrument consists of a small but strong iron frame, having a shank or plug forged upon one of its sides. This plug is $1\frac{1}{2}$ inches in diameter and $1\frac{1}{2}$ inches long, and is formed into a screw, the thread of which corresponds with a similar screw-thread cut into the outer portion of each of the holes in the side of the gun, by which means the frame may be secured to either of the holes, at pleasure. A small hole is bored through the axis of this plug, making a free passage to the caliber of the gun. A piston is nicely fitted to this hole in the plug, and thus the end of the piston receiving the whole force of the fired gunpowder will be driven outwards at each discharge. A large steel head or block is fitted upon the outer end of the piston, and from this head rises a py-

of these supposed analogies, but appeal first to the direct teaching of a simple experiment. Take, then, a little spring balance, such as is used at some of the post-offices for weighing letters, and which consists of a little pedestal and column, like a candlestick, which contains a spiral spring, and over the top is the pan, to hold the thing to be weighed. Now take any weight that will carry the pan just down to the top of the column when slowly applied. Half of this weight will carry the pan half-way down, if applied in the same way, but if you add, to this half weight, a small quantity, just enough to overcome the friction of the acting parts, and hold this upon the pan when at its full height, so as just to touch its surface, and then release it *suddenly*, the pan will descend to the top of the socket, or will mark twice

ramidal or lozenge-shaped point, or blunt edge. Against this edge, and firmly fixed in the frame, is a piece of thick copper. Now when the gun is fired, the piston, being driven outwards, forces this dull point or edge into the copper, and leaves a mark or impression upon it corresponding in depth to the force with which the piston was driven against it. By comparing an impression, made in this way, with another impression made upon another piece of copper by the actual pressure of weights placed upon a similar tool, Captain Rodman supposes that the force of the piston may be estimated very nearly. The reader will perceive, on reading a little farther in the text, that the force of the point, by which the impression is made by the instrument, is not the equivalent of the pressure upon the caliber of the gun, and that it was a gross oversight in Captain Rodman to consider them as equals. It will, of course, be understood, that, when one of the holes is used by the instrument, the others are closed by screw-plugs made to fit them.

the weight that it actually possesses. The cause of this must be so apparent to any one well acquainted with the laws of moving forces that I shall not stop to explain it here. Yet the action of the weight here is perfectly analogous to the action of Captain Rodman's instrument, or that part of it which is moved by the powder to make the impression, namely, the indenting tool, the block upon which it rests, and the little piston which receives the force of the powder. The mass of matter of which these are constituted is *fired* against, or into, the copper, as much as the ball is fired out of the muzzle of the gun. The analogy with the experiment of the spring balance is this: the indenting tool and its appendages are pressed forward by the gunpowder. The weight upon the spring balance is pressed down by gravitation. These pressures change the inertia in both cases into living force. This living force accumulates during the motion, from the gravitation in the weight, and the powder pressure in the gun, being, through the first half of the space, twice as great as the mean force of the resistance of the spring in the one case, and the copper in the other; and this accumulation is displayed in overcoming the resistance during a space equal to that first passed over.

We see, then, from the analogy of the weight falling upon a spring balance, that Captain Rodman's instrument ought to display and register double the force which he applies to it; even if it acts as freely

and undisturbedly as a spring balance, it cannot make less than a double register. But we shall see by and by that this is but a small part of the actual error; and yet Captain Rodman takes its register as true to within 1,000 pounds in cases, which he supposes to have been of pressure, of 90,000 or 100,000 pounds. He seems, indeed, to have had no suspicion of any error when his instrument gave indications of force wholly incompatible with the strength of the materials to which it was applied. Thus, at page 197, he takes the force which acted upon it at 100,000 to the square inch. Now the instrument in this case was held to the gun by a screw, formed into the cast-iron body of the gun, $1\frac{1}{2}$ inches in diameter and $1\frac{1}{2}$ inches deep. This gives an area of the *plug* of the instrument of 1.75 square inches, which received the full pressure of the fired powder. The pressure upon the end of the instrument then was $1.75 \times 100{,}000 = 175{,}000$ pounds, or about 80 tons. He must be a very bold engineer who would sleep under a weight of 10 tons suspended over him by a bolt tapped into a hole, in a cast-iron plate of $1\frac{1}{2}$ inches in diameter and $1\frac{1}{2}$ inches deep, and yet it does not seem to have occurred to Captain Rodman that 80 tons' pressure must have driven his instrument from its place.

But let us go a step further. Captain Rodman, at page 192 *et seq.*, relates a course of experiments which may be given in short hand as follows. He

made 18 cylinders of three different kinds of iron. They were all one foot long, and all bored out through their entire lengths with calibers two inches in diameter. They were then turned off on their outsides, so as to leave them of six different thick nesses, varying from each other from half an inch up to three inches. The variation being, of course, by increments of half an inch. Each kind of iron gave one cylinder of each thickness. The mean strength of the iron, as ascertained from specimens of each casting, being 26.866, say 27,000 pounds per square inch. These cylinders were then subjected to a bursting force produced by firing gunpowder confined within them. This was done for the purpose of ascertaining the power of cast-iron of these different thicknesses to withstand the force thus produced. The force was measured, by Captain Rodman's instrument, of course, and the first two columns in the following table give the strength of each thickness of metal according to Captain Rodman's mean: —

$\frac{1}{2}$	37842	25541
1	38313	38313
$1\frac{1}{2}$	63384	46057
2	80229	51085
$2\frac{1}{2}$	92270	54732
3	93702	57468

Upon seeing the enormous strength thus given to the iron, Captain Rodman merely remarks that the

bursting pressures are greater in the whole series than required by the tenacity of the iron, "even supposing the whole thickness of metal to resist uniformly as in tensile strain." But no doubt seems to cross his mind as to the accuracy of his instrument or his measures; he therefore proceeds forthwith to compute the force on the hypothesis "that the strain diminishes as the square of the distance from the axis increases." This means to reduce the power of the metal to sustain pressure, at different thicknesses, according to Barlow's formula. I have given his numbers in the third column above.

I confess I was puzzled for a long time to find out what these numbers meant. The tenacity of the iron used was 27,000 pounds to the inch; Barlow's formula gives for a cylinder 2 inches internal diameter and 1 inch thick, made of such iron, just half of this tenacity, or 13,500 pounds. I then went over all the different thicknesses according to Barlow's formula, and found even stronger cases of discrepancy than that here cited, and as I do not profess to be a mathematician of a very high order, while Captain Rodman has the calculus "familiar as his garter," I thought it was possible, after all, that I had misunderstood Barlow's rule. I therefore, laid down, in section, each of the cylinders in full size, and reqested three of the distinguished mathematicians of Cambridge to tell me, what must be the strength of each according to Barlow's rule. They all calculated separately, and

all agreed with each other and with me exactly, and I here give the whole matter in a tabular form.

1st column in this table, gives the thickness of the several cylinders.

2d column, the pressure per square inch, as measured by Captain Rodman's instrument, under which each cylinder burst.

3d. The pressure which the cylinders ought to have sustained according to Captain Rodman's computations, from Barlow's formula.

4th. The true pressure of burstings according to Barlow's *formula* as computed and applied by me, on iron having 27,000 pounds per inch, tenacity, — this being the mean tenacity of these specimens, as stated on p. 192.

5th. The errors of Captain Rodman's experiments, or, of his instrument.

6th. The errors of Captain Rodman's computations.

1	2	3	4	5	6
$\frac{1}{2}$	37842	25541	9000	28842	16541
1	38313	38313	13500	24813	24813
$1\frac{1}{2}$	63384	46057	16200	47184	29857
2	80229	51085	18000	62229	33085
$2\frac{1}{2}$	92270	54732	19286	72984	35446
3	93702	57468	20250	73452	37218

[NOTE. — The reader is requested to attend particularly to the 5th and 6th columns of this table, as these give the errors of the instrument, and of the computations.]

Now how is all this? Why, Captain Rodman in his computations took, not the coefficient of the true tenacity of 27,000, as laid down by Barlow, but the tenacity which his instrument gave for the cylinder one inch thick. Thus taking at 38,313 what should have been 13,500. Not only so, but the law of the inverse square, which he used, and which is Barlow's rule, makes it impossible that any of his last instrumental measures should be nearly right, even if the tenacity be increased from 27,000 up to 76,626, which is the number that he in fact uses. For, according to this law, a cylinder of two inches' internal diameter, made of cast-iron, or any *unmalleable* material, of 76,626 pounds' tenacity, can never be made thick enough to sustain a pressure of 76,626, or at least it cannot be done until some one shall contrive to make $1 \times x = 1 + x$, or 1 multiplied by 1 equal to 1 added to 1, a feat which Captain Rodman's instrument must have performed in giving several of the results above tabulated.

I do not think it will be necessary to pursue this instrument any further to show its utter worthlessness. It must be given up, and the whole family of results born of it must go with it.*

* I shall be excused for citing one other case, although it may be thought, by some, unnecessary. Captain Rodman gives at page 197, in his table, the force produced by firing 12.67 pounds of powder in an 11 inch gun, behind a shot of 186.4 pounds weight, at, in one instance, 100,000 pounds. Now this must have given a *bursting* pressure upon the walls of the gun of 1,100,000 pounds to every

I shall pass, therefore, from Captain Rodman's instrument to an examination of his gunpowder. When the newspapers, some time ago, gave the story of Captain Rodman's experiments with his 15-inch gun, there was a great account made of the strange kind of gunpowder used, the grains of which were said to be as big as pigeons' eggs. But Captain Rodman's book gives us the reason for the use of this very coarse powder. It is to avoid the great stress laid upon the gun by the rapid development of the gas or fluid, as produced by powder of common grain, from its quick combustion. Now, Captain Rodman proposes, by the slow combustion of these large lumps, not only to avoid the shock of the first explosion, but to continue the development of the force through the whole length of the bore. This would certainly make it much easier work for the breech portion of the gun; but the

inch of its length; consequently, if the gun was 11 inches thick, the iron to sustain this pressure must, if Barlow's formula be true, (and Captain Rodman makes no doubt of that, but uses it under the name of the inverse square,) have possessed a tenacity of 150,000 pounds to the inch. Not only will no cast-iron bear this strain, but no metal, nor any other substance whatever yet known to the art of man, is capable of bearing it. Even cast-steel, the strongest body known, when wrought down by the best hammering, will not sustain 150,000 pounds to the inch. Indeed, if a mass of iron gun-metal, though the strongest ever made, were cast as large as the Capitol at Washington, and then bored through with a caliber of 11 inches, it would, according to Barlow's formula, be split by a fluid pressure of, not 150,000, but 50,000 pounds to the inch.

fact of resorting to it shows the suspicion entertained by Captain Rodman of his gun's strength.

Let us, then, first see how far the idea of equalizing the pressure is obtained by increasing the size of the grain. To do this, I must resort to the measures given by Captain Rodman's instrument, which, though worthless as absolute measures, may yet give some rude approximation to comparative values when used upon the same gun and upon the same place, but with different grained powders. Turning to his book, then, p. 203, we find that a charge of 8 lbs. of powder grained to .1 of an inch diameter, gave against a 43-lb. shot a force of 51,800 lbs., 14 inches from the breech, and 6,700 lbs. at the distance of 84 inches, — these being the greatest and least forces; while a charge of 8 lbs. of powder of .4 inches' grain, or 64 times the former in size of grain, gave against the same shot 31,950 lbs. for the greatest, and 5,150 lbs. for its least force. The greatest force of the fine powder, then, was about 7 times that of the least force; while the greatest force of the coarse powder was about 6 times that of the least force. Surely this is no great advance in equalizing the forces between the breech and the muzzle of the gun. But let us see what it costs in loss of force from the use of the coarse powder. Taking the mean of these two extremes, as the true force in both cases, we have $51{,}800 + 6{,}700 \div 2 =$ 29,250 for the mean force of the 8 lbs. of fine

powder, and 31,950 + 5,150 ÷ 2 = 18,550 for the mean force of the large powder; from which it will be seen that it will require $12\frac{1}{2}$ lbs. of the coarse powder to produce the same force upon the shot that is produced by 8 lbs. of fine powder. The long and short of this whole matter of using the powder in lumps rather than grains, is a *mechanical adulteration*, and produces the same effect, namely, a slow combustion, such as may be produced by making the powder of materials *chemically adulterated*, or by mixing a portion of clay with the paste, or by moistening good powder before using it. This reduction of force may be carried to any extent by increasing the size of the grains or lumps, or by making it in *perforated* cakes, as Captain Rodman actually proposes to do.

But suppose that Captain Rodman's ideas of the advantage of a slow development of the force could be carried out, of what use would it be? I assert, although I am not yet quite prepared with a formal demonstration of it, that the same, or very nearly the same, quantity of iron will be required in the gun, the iron being used in the manner pointed out by me in 1855, to give the same velocity to a given shot, under whatever law the force is developed, between the limits of the quickest powder now used, and one of equable force development; and that, to produce this force with the least expenditure of powder, the development of the force should be made as quick as possible.

I now pass to an examination of Captain Rodman's proposal to use hollow shot. Having, as it seems to me, laid his powder under as great a contribution as it would bear, to avoid putting too much stress upon his gun, he proceeds to put the same tax upon his shot, and he assesses it by taking 9 inches from the heart of every 15-inch shot, thus reducing its weight from about 425 pounds, to about 320 pounds. In the mediæval times, when guns and gunnery were in their infancy, stone balls were used. The lightness of this material saved the imperfect *bombards* from destruction. The effect of these balls was of course very small, compared with the heavy, solid iron shot, brought into use in a later age. Are we to return to the mediæval practice? This certainly seems a step in that direction.

Sir Howard Douglass, in speaking of the terrible effect of the fire of the American frigates in the war of 1812, says that some of them used shot weighted by a leaden core. This I believe is not true, but it shows the opinion of this old engineer, of the advantage that might be expected from increasing rather than diminishing the specific gravity of cannon-shot. Yet Captain Rodman's hollow shot seems to be looked to, pp. 289, 307, as the missile to meet iron-plated ships. Whether it is intended to explode them against the ship, or to depend upon their direct percussion, is not very clearly stated. The effect would probably be very much alike in both

cases. Indeed, Captain Rodman admits, p. 298, that, although "none of these broke in the gun, some did break in the sand-bank after the sand had been packed hard by repeated firing." God forbid then, that we should ever have to try them against the sides of the Gloire or the Warrior.

I have thus examined some of the prominent points in the labors of Captain Rodman, as they are detailed in his reports, and, without, as I hope, making any remark disrespectful to him as an officer and gentleman, I have declared freely what seems to me the value of the most important of the experiments and conclusions given in his work. Repeating here what I declared in an earlier part of this paper, that I think well of his method of cooling the hollow casting which is to form a gun; I think that there is good reason to believe that these guns will be somewhat superior to those made in the usual method. In the practice of casting in this way, however, great care must be observed to avoid the explosion which may occur should the cooling water find its way from its conductor into the body of the mould.

But, after all, what chance has any cast-iron gun, especially smooth-bore gun, to stand before the kind of gun proposed by me in 1855, if that be once adopted and executed in the rifled form? It might have been said when this plan was first promulgated, its principles pointed out, and its advantages demonstrated, that, however perfectly I had tested, by prac-

tical trial, the superiority of my guns, made twelve years before, of wrought iron and steel, no such practical test had been made upon the peculiar form last proposed. This objection can now no longer be made. If I have been prevented, or denied the opportunity of giving the practical test myself, others have partially done it for me. This has been effected, first, by Captain Blakely, an able and scientific officer of artillery, in England, who filed a specification there, soon after the date of mine, for an improved gun upon the same principle that is given by me. He did this no doubt from his own original conceptions and, although he failed in his first trials, probably from want of practical knowledge, yet he soon after constructed a gun having a few hoops, only, upon the breech, which he claims to have been the strongest gun ever made. His claim was thus carried to terms a little too high, from his not remembering, perhaps not knowing, the strength of my 6-pounder wrought-iron guns, made fifteen years before. However this may be, no one now doubts the great strength of his guns, as they are called in Europe.

Again, Mr. Whitworth, who has carried on such a sharp opposition to Armstrong, uses hoops strained on to the body of all his large wrought cannon.

So, at last, in this country, Mr. Parrott has *reinforced* his cast-iron rifled cannon with a wrought-iron hoop shrunk upon the body of the gun, between the breech and the trunnions, and by this imperfect or

partial application of a form and principle which I have taken so much pains to develop, he alone has succeeded here in producing an effective rifled gun. The legal right of Mr. Parrott to use this piece of my structure will soon be submitted to the proper tribunal.

Last of all, and what must be considered as decisive of the merits of the principle of imparting strength by the strained hoop, the Spanish government have lately published the report of a commission appointed to take the whole subject of rifled cannon into consideration, and decide upon the question of which is the best form. This commission, after a thorough and laborious investigation, gives its decision clearly and decidedly in favor of the hooped gun, under the name of Blakely's gun, over all others. A printed account of this report, from the Scientific American, is herewith transmitted.

Permit me then, Gentlemen, in conclusion, most respectfully, but earnestly, to urge your attention to, and adoption of, the principles and method of making cannon proposed by me, and demonstrated to be the most perfect method which has been devised to obtain the greatest strength and endurance for these great instruments of war.

I am, Gentlemen, very respectfully,

Your most obedient servant,

(Signed,) DANIEL TREADWELL.

[Note. — I cannot conclude, without asking the scientific engineers of the country, if they are willing that a work like this, which I have examined, shall be taken by other nations, and by posterity, as giving a representation of the practical science of the United States in the year 1861? But as it is printed at the public expense, and with the *imprimatur* of a high official board, it will be taken as such, unless its errors, of which I have struck at a few of the more prominent ones, are pointed out to, and if possible disavowed by, those who ought never to have suffered the work to appear under the stamp of official approbation.]

ON THE

CONSTRUCTION OF HOOPED CANNON;

BEING

A SEQUEL TO A MEMOIR

"ON THE PRACTICABILITY OF CONSTRUCTING CANNON OF GREAT CALIBER, ETC.,"

PUBLISHED IN THE

MEMOIRS OF THE AMERICAN ACADEMY, IN THE YEAR 1856.

BY

DANIEL TREADWELL,

LATE RUMFORD PROFESSOR IN HARVARD COLLEGE.

FROM THE MEMOIRS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES, 1864.

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ON THE

CONSTRUCTION OF HOOPED CANNON.

[From the Memoirs of the American Academy of Arts and Sciences, 1864.]

Although a great improvement has been made in the construction of cannon by the adoption of the principle, and imperfectly the mechanical form, indicated by me in a Specification of June 19th, 1855, which was immediately afterwards expanded into the Memoir published in the VIth Volume of the Academy's Memoirs;* still, many points in the theory of that construction remain not only unperfected, but almost unexamined.

It is my purpose, therefore, in this paper, to investigate several important properties and laws which are inherent in the materials of which the gun described in my former memoir is constructed; and from this investigation I shall endeavor to draw such instruction as will enable us, if not to perfect,

* The memoir in the VIth Volume must be considered as a sequel to, and a further development of, the principles contained in a publication, in the form of a pamphlet, made by me in 1845. In this pamphlet, not only the principles, but the method of construction since followed by Armstrong and others, are fully pointed out.

at least to understand and improve, the theory of construction. The investigation will be founded almost entirely upon certain peculiarities in the nature, character, and properties of the materials (wrought-iron, cast-iron, and steel) of which the guns, constructed upon the principle heretofore published by me, are formed.

With these preliminary remarks I enter at once into the proposed inquiry, leaving the development of the course to be pursued to appear as I proceed.

In the memoir of 1855, before referred to, in giving an account of the theory of hooping cannon, I inserted the following paragraph (p. 10):

"There may, at the first view, seem to be a great practical difficulty in making the hoops of the exact size required to produce the necessary compression. This would be true if the hoops were made of cast-iron, or any body which fractures when extended in the least degree beyond the limit of its elasticity. But wrought-iron and all malleable bodies are capable of being extended without fracture much beyond their power of elasticity. They may, therefore, be greatly elongated without being weakened. Hence we have only to form the hoops *small in excess*, and they will accommodate themselves under the strain without the least injury."

And again, in a note, I said: "Mr. Barlow does not limit the application of his investigation to any kind of material, but it is evident that his conclusions are not applicable to any *malleable* metal like

bronze; for in a cylinder constructed of hoops of this material, the inner hoops may be elongated by the pressure acting as a *crushing* force, and by this means be enlarged without any diminution of tenacity. Perhaps some kinds of soft cast-iron may accommodate themselves to an enlargement in the same way. But with hard crystalline cast-iron, no actual displacement of the constituent particles can take place without fracture; and although the effect of the fluid as a crushing force may act as an auxiliary to the strain, as any estimate of its amount would be a mere guess, I shall not attempt any modification of Mr. Barlow's conclusion, when applied, as in this case, to hard cast-iron gun-metal."

However important I might have considered the effects of the crushing force, and the partial or imperfect malleability of cast-iron, by which the gun may be permanently distended, a further examination of the subject has convinced me, that Mr. Barlow's theory must be in all cases modified and limited by the elongation or yielding from this malleability under the crushing pressure of the fluid; and, in many cases, as where the material is bronze or wrought-iron, the whole theory must be discarded as inapplicable. To show this, I will state the following experiment. I took a ring or hoop of wrought-iron, made up of four concentric rings, one placed over another, after one of the methods practised by me in making my wrought-iron guns in 1840–1843. These rings, when welded together, formed a hollow cylinder 1 inch long, having an internal diameter of

$1\frac{1}{2}$ inches, and an external diameter of 3 inches; consequently its walls were $\frac{3}{4}$ of an inch thick. This cylinder, after being smartly hammered or sledged when cold, was subjected to distension by driving into it a conical plug or pin, by blows with a heavy sledge. By this means the inside diameter was increased to $2\frac{1}{8}$ inches. This distension, from $\frac{1}{8}^{2}$ to $\frac{1}{8}^{7}$, was far from rupturing the ring, although it produced a great number of minute fissures upon the outside, while the inside did not show the least sign of crack or flaw.

I should remark, that this ring was made of very tough Norway iron; but, although I made several others in the same way, and of common English as well as of American iron, none of them broke under the strain before a distension of $\frac{1}{10}$ of their inside diameter; and, in all cases, the fracture commenced upon the outside and worked gradually inward to the caliber.

Another thing, worthy of all attention, was this: The end of each cylinder or ring showed, after welding, the thickness of each of the several concentric rings of which it was formed; and after the distension, the greater diminution of thickness in the inner and smaller rings was very apparent; thus showing how much greater was their distension or elongation, circumferentially, than that of the rings outside of them; and furnishing an experimental exemplification and corroboration, if such corroboration were required, of the fact first geometrically demonstrated by Barlow, and upon which he founded his

theory explaining the weakness of cast-iron hollow cylinders when exposed to an internal pressure. Now, although the fact is to be received as he has demonstrated it, yet it becomes evident that the theory and formulas founded upon it must be limited, rigidly, to unmalleable bodies, and is in nowise applicable to cylinders of wrought metal, like the rings or hoops experimented upon by me. For, to bring a case under the conditions or facts supposed to operate in that theory, the fracture must begin upon the inside, which is supposed to be distended, like a rod strained by a suspended weight. But, in my experiments, not only was the innermost part of the cylinder subjected to the straining force of the conical pin, tending to rupture the whole thickness of the cylinder, but the inner portion of it, to a certain depth outward, was placed between two opposing forces, viz. the pressure of the conical pin in one direction, and the binding strength of the external portion of the cylinder in the other. Between these two forces it was crushed or pressed and extended laterally, and thus made thinner and longer, as a bar or sheet of metal is under a hammer, or between the rollers of a mill. Under these conditions it could not fracture before the external portion; for, to fracture a body, its integrant atoms or molecules must be separated; but in this case they were pressed together. This crushing pressure of the conical plug differed in no essential form from that produced by fired gunpowder. So the fracture commencing upon the outside of the ring is similar

to that made in the bursting of bronze guns, which always commences upon the outside. The same fact was observed by me, twenty years ago, in the trial, to extremity, of two 32-pounder wrought-iron guns. In both of these, the fracture began upon the outside and worked slowly inwards.

The preceding statement cannot fail, I think, to convince any one that Mr. Barlow's theory is wholly inapplicable to guns made of wrought-iron, or any like malleable material, and, indeed, is to be applied, in its complete and unlimited extent, only to such materials as highly hardened steel, glass, and those crystalline or wholly unyielding bodies, in which the ultimate particles or molecules are incapable of being made to change place permanently in relation to each other, but in which the limit of elasticity ends in complete separation or fracture. When applied to hollow cylinders made of substances of this latter kind, it is probably true to the letter. But what is cast-iron? And are we to be guided by Barlow's theory in computing the strength of cannon made of this material? Believing, as I do, that most kinds of cast-iron are, to some, though a very limited extent, malleable, or, at least, that they admit of some small permanent change of form without fracture, we ought not, in my judgment, to apply Barlow's theory, without some modification, to express the strength of guns made of such material, as they really possess greater strength than the formula given by that theory assigns them; though for many of the harder and completely crystalline kinds

of iron we must consider it applicable, as a safe, if not an entirely accurate, guide for practical purposes.

Following this property of malleability, from the cast-iron, or body, of the gun to the wrought-iron or steel hoops with which the body is encircled and compressed, let us next see what method of constructing the hoops should be adopted to obtain the greatest strength to the gun.

It is a fact well known to all smiths, or actual workers in the metals, and to many engineers, whose knowledge is often derived principally from books, that all the metals, by being subjected for a considerable time to hammering, rolling, or wire-drawing, acquire a great increase of elasticity and hardness. Indeed, if any of these processes be carried beyond a certain extent, the metal loses its malleability and ruptures or cracks under the continued operation. The hardness and elasticity thus induced are, however, easily destroyed, and the original malleability is restored by simply subjecting the hardened metal to heat, which should be considerably below its melting point. For tin, it is said that the heat of boiling water is sufficient for the purpose. But for gold, silver, copper, and iron, the heat of about 1000° is required to produce this *annealing* effect. For iron, it should be carried to a full red heat, whatever temperature that may be.

Now, for the purpose of ascertaining, with some degree of precision, the difference in hardness, tenacity, and elasticity, between a piece of iron subjected to various degrees of heat from 400° up to that

which produces a thoroughly annealed state, that is, a full red heat, and the same iron after having been subjected to some one of the hardening processes before mentioned, I have made a great many experiments upon iron wire of various sizes, and in various states as produced by previous working and heating. I will now relate the mode of making a few of these experiments and the results obtained from them, which results were in accordance with numerous others obtained by the same method of operating.

These experiments were made upon pieces of iron wire about fifteen feet long and of different sizes. The instrument for performing the experiments consisted of a long horizontal frame, to one end of which was affixed a strong steelyard, which was bent into the form of a bell-crank; and the shorter arm of which was vertical, while the longer arm, upon which hung the poise, was horizontal. One end of the wire to be experimented upon was connected with the shorter arm by being turned a few times about a ring which was connected with the arm by a free joint. The other end of the wire was fastened, by similar means, to a strong bolt fixed to the frame at a distance of fifteen feet from the steelyard. Connected by cramping it with the wire, near the end last described, was a stiff wooden rod, which lay upon the frame, and passed, by the side of the wire and parallel with it, to near that end which was connected with the steelyard. To the neighboring end of the wooden rod was fixed a

smooth tin plate, about one foot long and five inches wide. This plate lay upon the frame, immediately under the wire and nearly in contact with it; and upon the surface was registered, by a fine needle-point, the changes in the length of the wire under different tensions. To do this, a short straight-edge, or ruler, was firmly cramped to the wire, directly over the register-plate, so that, when a line was drawn upon the register-plate by the needle, which was laterally pressed against the edge of the ruler, its direction would be across the register-plate, or at a right angle with the axis of the wire. The distance from the point upon the wire where the rod connected with the register-plate was cramped to it, to the point where the straight-edge or ruler was cramped, was exactly 140 inches; and it will be seen that, by the arrangement here described, whatever yielding or springing might take place in the frame, in the bolts, in the steelyard, or in the wire itself outside of the 140 inches comprised between the points at which the rod of the register-plate and the straight-edge were respectively cramped, could not affect the accuracy of the measure of any change in the wire between those points, and that the straight-edge could not change its place upon the register-plate in the direction of the length of the wire, unless the length of the wire itself was changed in an equal degree.

The following four experiments, made on wire of ordinary quality, from the same hank, will give sufficient warranty to the conclusions afterwards drawn

from them. The results here given are, as I have before remarked, altogether in accordance with other results obtained by the same mode of operating upon other wires.

The wire used in the experiments now given was $\frac{100}{1075}$ of an inch in diameter, and, consequently, the area of its cross-section contained .006789 of a square inch. Having taken a piece of this wire about sixteen feet long, hard as it came from the draw-plate, I straightened it and fixed it upon the testing apparatus in the manner before described; and, after cramping to it the register-plate and the ruler, I commenced the operation upon it by letting the steelyard draw upon it with a weight of 10 pounds, for the purpose of taking out the sag, and to bring all the bearings into place. I then drew a line, directed by the straight-edge, as before described, upon the register-plate. This line is shown in *Figure* 1, marked *Zero A.* I then placed the poise of the steelyard so as to give to the wire a tension of 40 pounds. This weight elongated the 140 inches of wire, carrying the ruler over the register-plate the distance shown by the interval between the short line and the zero line at the left-hand end of the latter and immediately under it; and this short line (seen above the number 40) was then made by the needle-point, guided by the ruler. The poise was then removed from the steelyard, when the wire returned to its original length, as was shown by the ruler again coinciding with the zero line. The poise of the steelyard was then placed so as to strain

the wire with 80 pounds, and the distance of the short line (seen above the number 80) from the zero line, shows the lengthening of the wire under this strain. On removing this weight, the wire again returned to its original length; and, on repeating the operation so as to give the wire the several strains of 120, 160, 200, and 240 pounds, the several elongations, shown in the figure by the distances of the short lines (seen over these numbers) from the zero line, were produced; but from each of these elongations the wire recovered its original length on being released from the strain. On carrying the strain, however, to 280 pounds, the wire became permanently elongated, as was shown, on its release from the strain, by the small quantity denoted by the distance from the zero line of the short line immediately under it; while the permanent elasticity was shown by the distance of the two short lines from each other (as seen over the number 280). The operation was then continued by successively giving to the wire, and again removing from it, the loads of 320, 360, 400, and 440 pounds; and the effects are graphically shown in the figure by the distances between the zero line and the nearest short lines, which distances represent the permanent elongations, while the distances between the short lines themselves represent the permanent elasticity, after the strain of each load.

The register-plate was then moved upwards a little upon the rod, and a new zero line, B, (*Figure* 2) was marked upon it. With this I began as before, by

Fig. 1. WIRE, hard, as it came from the draw-plate; 140 inches long, $\frac{100}{1075}$ths of an inch diameter. Area, .006789 square inches.

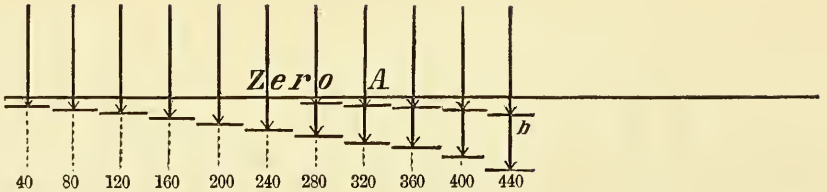
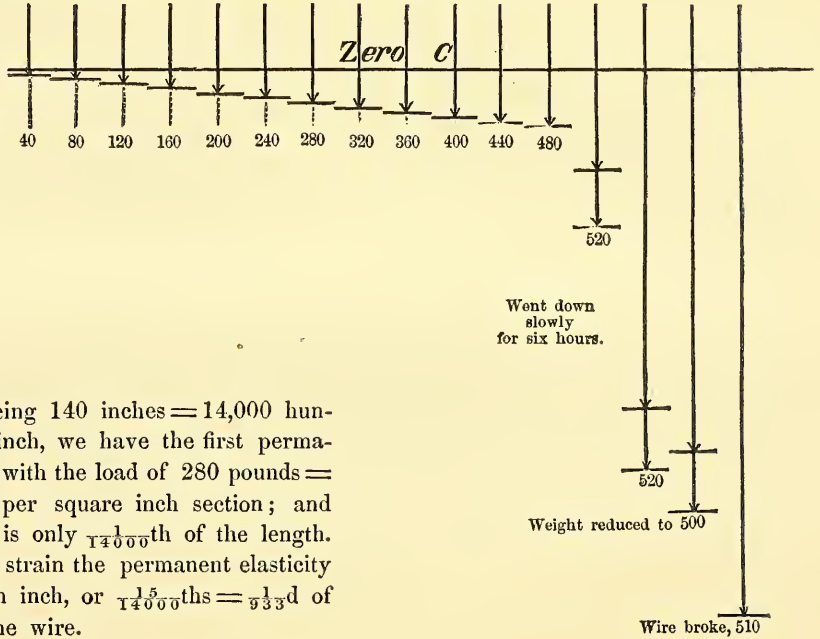


Fig. 2. SAME WIRE, after the above strain.

Fig. 3. SAME WIRE, after being heated, when under a strain of 40 pounds, so as to burn oil upon it, through its whole length. Temperature estimated at 850°.



The wire being 140 inches = 14,000 hundredths of an inch, we have the first permanent elongation with the load of 280 pounds = 41,241 pounds per square inch section; and this elongation is only $\frac{1}{14000}$th of the length. With the same strain the permanent elasticity is $\frac{15}{100}$ths of an inch, or $\frac{15}{14000}$ths = $\frac{1}{933}$d of the length of the wire.

placing upon it a strain of 40 pounds, and then, in succession, 80, 120, 160, 200, 240, 280, 320, 360, 400, and 440 pounds; removing each in like succession, to see if any permanent elongation would be produced by this repetition of the strain. As might have been expected, none whatever was produced, but the ruler returned in each case to the zero line, as shown in the figure. But, on increasing the strain to 480 pounds, the elongation shown at *c* was produced.

Knowing that the strain had reached nearly the limit of the strength of the material, I then subjected the wire to the heat of two large pieces of iron heated to a glowing red, and passed, one above and one below, in contact with the wire. By this means the wire was heated to such a degree that oil burned freely, on being dropped upon it, through its whole length. The wire was kept connected, in its place, with the apparatus during this heating operation, and it was likewise kept straight by a tension of 40 pounds from the steelyard. The temperature to which it was raised could not have been less than 850°. After it was cold, the register-plate and the ruler, which had been removed, were readjusted upon it, and a new zero line, *C*, was marked. (See *Figure* 3.) The weights were again applied to and removed from the steelyard as before, and the effect produced by each strain was marked, as shown in the figure, above the respective numbers. No permanent elongation was produced up to the strain of 480 pounds, the same result that was before reached. The elasticity, therefore, remained unimpaired by the heating. But,

this load of 480 pounds being very near the tensile strength of the wire, on increasing it to 520 the great stretch shown in the figure, above this number and immediately below the zero line, was produced. Still, on taking off the load, the wire exhibited its old elasticity, and this even a little increased. This load, replaced and continued for six hours, carried the elongation much further, as shown in the figure; and so nearly was the breaking-point reached, that the elongation continued even after the load was reduced to 500 pounds, and the wire finally broke after it had been elongated the $\frac{1}{51}$st part of its length under a strain of 510 pounds, thus showing a tensile strength of 75,120 pounds to the square-inch area.* The permanent elasticity had reached, just before the fracture, or when the load was 480 pounds (equal to 70,700 pounds per inch area), $\frac{3}{140}$ of an inch, or the $\frac{1}{466}$th (.00214) part of the length of the wire. Other experiments were made by exposing the wire, which was the subject of them, to the heat of melted lead. Here, in two cases, the wire was passed slowly under the surface of lead which was kept very much above its melting temperature. These wires, when tried afterwards in the testing machine, showed their previous elasticity unimpaired.

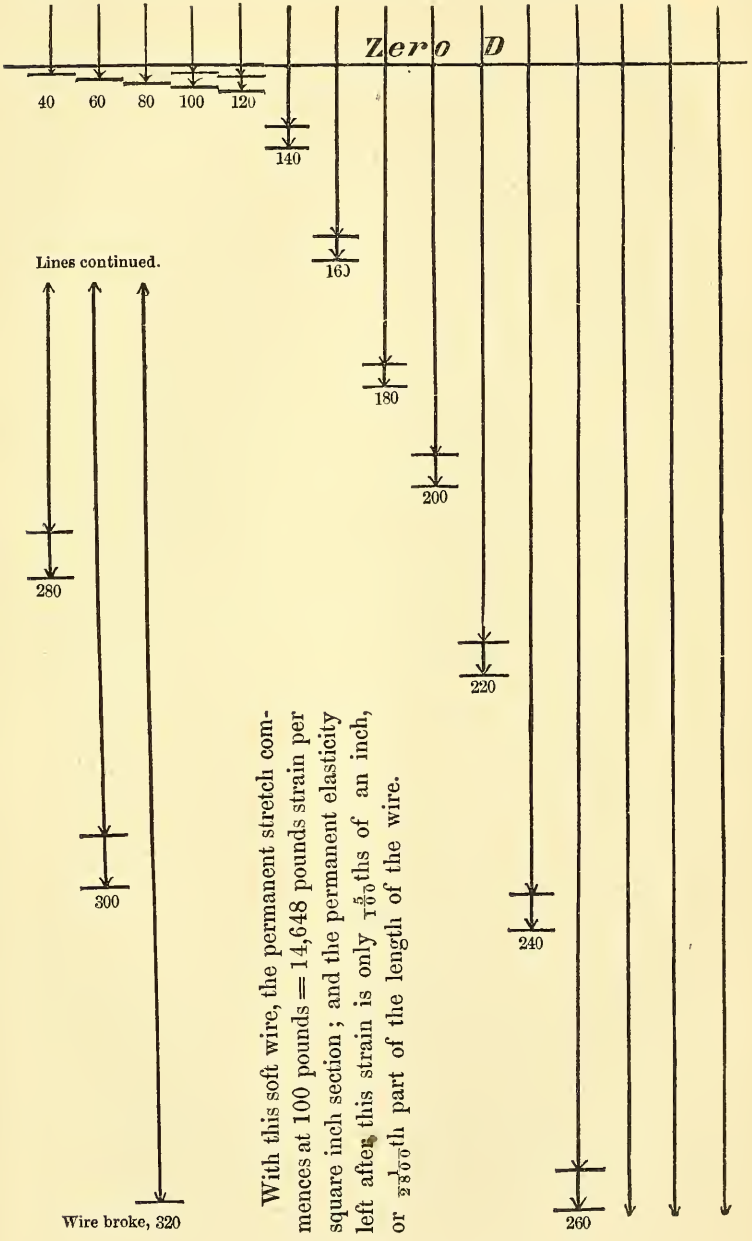
* The following numbers represent the weight upon the wire when reduced, or computed, for a square bar of one-inch section: —

40 = 5,891	200 = 29,458	360 = 53,025	520 = 76,592
80 = 11,783	240 = 35,350	400 = 58,917	560 = 82,433
120 = 17,675	280 = 41,241	440 = 64,808	
160 = 23,596	320 = 47,128	480 = 70,700	

The fourth experiment that I shall relate, was made upon a piece of wire from the same hank with that before used, after it had been annealed to a full red heat. This, after having been straightened, was placed upon the testing machine, and subjected to a succession of strains, commencing at 40 pounds, and increasing by steps of 20 pounds each (instead of the 40 pounds before used) up to 320 pounds, under which strain the wire broke; thus showing an ultimate tenacity of 47,128 pounds per square inch, or, allowing for the diminution of the area of the wire by the elongation previous to breaking, about 51,000 pounds, instead of 75,120 pounds, as given in the former case. The permanent elasticity had reached, just before the fracture, or when the load was 300 pounds upon the wire (or 44,186 pounds per square inch), $\frac{2}{100}$ of an inch, or the $\frac{1}{538}$th part of the original length of the wire. The effects of the various increasing strains are fully exhibited in *Figure* 4 (next page), which (as is also true of the preceding figures) shows a true copy of the lines made upon the register-plate. By this it will be observed that the permanent elongation commenced at a strain of 100 pounds, and increased rapidly, at each successive increase of weight, until it reached a length of $10\frac{1}{4}$ inches, or the $\frac{1}{136}$th part of the length of the wire.

Now, on comparing the results shown in all these figures, we see that these experiments demonstrate with some degree of precision several physical facts, all of which are of high importance in the construction of cannon upon the principle pointed out in the

Fig. 4. Wire from same hank after it had been fully annealed.



With this soft wire, the permanent stretch commences at 100 pounds = 14,648 pounds strain per square inch section; and the permanent elasticity left after this strain is only $\frac{5}{100}$ths of an inch, or $\frac{1}{2800}$th part of the length of the wire.

Memoir to which this is a sequel. These facts are: —

First, That with a piece of iron hardened by compression and tension, in the condition of hard wire, the amount of permanent elongation is far smaller than the permanent elasticity up to near the breaking-point, and also that the permanent elongation does not begin until about one-half of the breaking strain is applied.

Second, That the part of the elongation, or stretch, which is within the elastic power of the wire, increases very regularly under equal increments of strain; thus exhibiting the truth of the maxim, *Ut tensio, sic vis* — As the stretch, so the strain. But the permanent elongations made by the same increments of strain, especially when near the breaking of the wire, are entirely at variance with this maxim. This will be seen in *Figure* 4, where an increment of 20 pounds to an existing strain of 120 pounds, produces a permanent stretch of $\frac{5}{16}$ths of an inch, while the same increment of 20 pounds, when the wire was under a strain of 280 pounds, increased the length, permanently, full $1\frac{1}{2}$ inches.

Third, That, when the material has been subjected to a strain of a given amount (say 440 pounds, as in *Figure* 1), the repeated application of a strain within that amount produces no further permanent elongation.

Fourth, That the subjecting of the same material to a heat sufficient to burn oil in contact with it (sup-

posed in this case to be 800° Fah., at least), will not impair its elasticity.

Fifth, That, when the iron is annealed, the permanent elongation commences at a comparatively low strain, and that its extent is very large in proportion to the elasticity of the iron, which shows how inappropriate is the use, upon a cast-iron body, of a hoop that has been heated to an annealing temperature; as it must be loosened, or suffer the cast-iron to break within its grasp, before a strain upon it up to half its tensile strength shall be reached.

Guided by the conclusions derived from the preceding experiments, I will now proceed to compare, with such precision as the knowledge thus opened to me permits, two guns constructed upon the principles and after the proportions given in the Memoir of 1855, both of these guns being supposed to be of the same size, and made of the same quality of iron throughout, but differing only in this, viz., that, in the one, the hoops are put upon the body in an annealed state; and, in the other, in such a state of hardness, produced by cold hammering and stretching (as hereafter described), as shall bring the iron, as near as may be, to the state of the wire represented in *Figure* 3.

These guns may be shortly described as having a caliber of 14 inches diameter; bodies of cast-iron, 7 inches thick in the reinforce, so as to make the external diameter of the body there 28 inches; and a covering of wrought-iron hoops in two layers, having together an equal thickness of 7 inches. The

strength of these cast-iron bodies, as shown in detail in the former Memoir, if made of cast-iron of 30,000 pounds tensile strength, when reduced according to Mr. Barlow's formula (which is recognized as sufficiently perfect for a practical guide), will be 210,000 pounds for each inch in length.

Now, let us suppose one of these bodies to be hooped with two layers of hoops, $3\frac{1}{2}$ inches each in thickness, these hoops being made of wide bars of wrought-iron, coiled like a ribbon wound upon a block, and in this state the coils being welded so as to form one ring, or hollow cylinder, or hoop.* The hoops, being thus formed and properly forged to shape and size, are supposed to be left in an *annealed* state; and, after being bored and finished to .001, .002, or even .003 of their internal diameter less than the part of the body that they are to enclose, we will suppose them to be heated and put in their place, where they cool and compress the cast-iron, being themselves at the same time strained and stretched by the resistance of the enclosed body. Now, whatever proportions this compression and this stretch may bear to each other, it must be evident, from an inspection of *Figure* 4, that, when the strain upon the hoops, from the shrinking, reaches 17,675 pounds per square inch (equal to 120 pounds upon the wire), they will receive a decided permanent

* A more full account of this method of forming rings may be found in the pamphlet published by me in 1845, or in "English Printed Specifications," No. 10,013; enrolled in July, 1844; printed in 1854.

elongation. Let us suppose, then, that the hoops are grasping the body with this force of 17,675 pounds per square inch, at the instant when the fired gunpowder has distended the cast-iron to its normal diameter. We see by the *Figure* 4, that by a further distension of the body the resistance of the hoops will be very slowly increased. What will this resistance amount to, when the cast-iron is distended to its breaking point? Although we cannot determine with any great accuracy how far the cast-iron can be distended before fracture, we may, I think, be very certain that a fracture would be produced by repeated firing under an enlargement of $\frac{1}{1000}$ part of its external diameter. But it will be seen by the figure, that a strain upon the wire of 160 pounds, or 23,596 pounds per inch section, produces an elongation of the wire of .9 of an inch, or $\frac{1}{155}$ part of its length; and it must be evident, that, long before this elongation and distension in the hoops are reached, the cast-iron must give way and the gun be destroyed. But, even allowing the gun to hold together up to the strain of 23,596 pounds per square inch upon the cross section of the hoop, we have the following computation of the strength of the gun, for each inch in the length of the reinforce: Cast-iron body, 210,000 pounds per square inch; wrought-iron hoops, 23,596 pounds per square inch, and, as both sides give 14 inches thickness, $14 \times 23{,}596 = 330{,}344$ pounds for each inch in length, and $210{,}000 + 330{,}344 = 540{,}344$ pounds for the strength through each inch in the length

of the reinforce of the gun of these dimensions and proportions.

Let us next suppose a gun to be constructed, in size and material, like that just given, but having this single difference in the method of preparing the wrought-iron hoops: that instead of placing them upon the gun in an annealed state, such as is represented by the wire from which *Figure* 4 was formed, they shall be subjected to a process of cold hammering and stretching, so as to bring them into the same condition, as near as attainable, with that of the wire used in making *Figures* 2 and 3.

Computing the strength of a gun covered with hoops brought into this state of hardness and elasticity, we have the diameter of the body, as before, 28 inches. Let the hoops be .001 part of their diameter less than the body, or 27.972 inches.

The hoops thus made, and expanded by heat, and placed upon the body, will, when cold, compress the body to a diameter somewhere between 28 and 27.972 inches, — the exact degree of compression depending upon the power of the body to resist compression, and that of the hoops to resist distension; but, when the force of the fired gunpowder is exerted upon the caliber, and the external diameter of the body is distended to its normal dimension of 28 inches, the power of the hoops to resist further distension will become 35,350 pounds for every inch area of their cross-section (this being equal to 240 pounds' strain upon the wire).

From this point the distending force of the gun-

powder will be resisted, both by the hoops and by the body; and, if we suppose the cast-iron body, in this as in the last case, to be fractured only after a distension of $\frac{1}{1000}$th part of its normal external diameter, we shall find that that point will not be reached until a strain of more than 70,700 pounds per square inch (shown by 480 pounds upon the wire) has been exerted upon the hoops. Then, taking the body, as before, to resist with a force of 210,000 pounds per inch in length, we have, as the whole strength of the gun: Body 210,000, and hoops $14 \times 70{,}700 = 989{,}800$, making together 1,199,800 pounds for each inch of its length, — decidedly more than twice the strength shown in the former case, where the hoops were annealed before being put in place.

In this statement, I have taken the comparative diameters of the body and the hoops at 28 and 27.972 inches. Now this difference is so small, that it cannot be produced in practice with geometrical precision; nor is this necessary; all that is required being, that the difference shall not be *less* than that here given, though a deviation by which the difference of diameters shall be twice, or even thrice, as great as this, will not affect injuriously the construction.

Thus, suppose the hoops, instead of being 27.972 inches, be made 27.916 inches, in diameter. A heat of 800°, to which the hoops may be heated without affecting their elasticity, will expand them to 28.064 inches, thus giving a margin of .064 or about $\frac{1}{16}$th of an inch, for play, and imperfect workmanship, when the hoops are run on to their places. In this case,

although the first compression of the body would be greater than if the hoops were made of the exact size assigned, yet the first discharge of the powder would, by a little permanent elongation of the hoops, bring them to the true diameter, without enlarging them beyond their elastic limits.

In the preceding computations of strength, I have confined myself to that manifestation of it which preserves the gun from longitudinal fracture. But a gun may be fractured transversely, or diagonally, as well as longitudinally, although I have heretofore fully proved, that, if made of a material which has an equal strength in each direction, the gun, or any hollow cylinder, has a vastly greater power of resisting cross, than longitudinal fracture. This is likewise applicable to any diagonal fracture. But as these guns owe their superiority in a great degree to their being formed, in part at least, of fibrous wrought-iron, the direction of the fibres being in the circumference of the gun, and moreover not perfectly integrated with the cast-iron as making one piece with it, it becomes necessary to consider the resistance to cross-fracture.

By a recurrence to the former Memoir, it will be seen that the cast-iron body alone, if possessed of a tensile strength of 30,000 pounds per inch, may be relied upon for preserving the gun from cross-fracture. But I cannot say that I have always been without some shade of doubt, whether the cast-iron, when exposed to the crushing force between the fired powder and the hoops, would exhibit the same resistance to cross-fracture that it would when free from this con-

dition. It was in some degree to guard against any defect that might possibly arise from this source, that I proposed that the hoops be made in two layers, and be fitted to the body and to each other, by a screw-thread. In this case the screw was not to exercise its usual function of a mechanical power; but to serve, by the interlocking of the threads upon the body with those of the hoops, to so cramp the two together, that the body could not be fractured crosswise without either stripping the thread through a space equal to at least half the length of the hoop, or fracturing the hoop crosswise before or at the instant when the body gave way. Now, to strip the thread of a screw through half the length of the hoop would require a force sufficient to make a shear cut, through a section of metal equal to at least one-third the internal surface of the hoop. The inner surface of the inner hoop, being $28 \times 3.14 = 88$ inches in circumference and 15 inches long, gives a surface of 1,320 inches, one-third of which is 440 inches. To strip or cut through a screw-thread forming a section of this magnitude, taking each inch to require but even 30,000 pounds, demands a force of 13,200,000 pounds, while, as is shown in the former Memoir, the whole force of the charge tending to produce cross-fracture is but 4,896,000 pounds, being the pressure of 32,000 pounds per square inch upon 153 inches, — the area of the caliber. The other alternative, that of fracturing one of the hoops at its weakest point, that is, where it breaks joint with two of the hoops of the other layer, and where, of course, one thick-

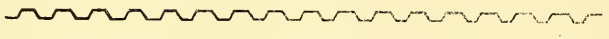
ness alone gives its support against cross-fracture, furnishes the following computation: The area of the cross-section of the inner and smaller hoop, contains 346 square inches, which, giving the iron, in this its weakest direction, a tensile strength of 40,000 pounds per inch, shows that a force of 13,840,000 pounds will be required to tear the hoop asunder.

The preceding computations, therefore, place it beyond doubt, that, even allowing that the lateral pressure of the fired powder upon the cast-iron body of the gun may impair the tensile strength of the body in resisting cross-fracture, yet, under this condition, and thus admitting as a truth that of which we have no evidence, we see that we may rely with perfect confidence upon the strength of the hoops alone, when secured to the gun by the screw-thread, as described in the former Memoir, to preserve the gun from cross-fracture.

In the Specification and Memoir before mentioned, I propose to form the screw "of about eight threads, each thread taking about one-eighth of an inch space, so that one turn advances each thread one inch," and "to make the threads of the female screws sensibly finer than those of the male, to draw by the shrink, the inner rings together endwise." The advantage of this form of construction will appear in this: that by the rapid advance of the hoop to its place, the shrinkage from cooling during its passage over the body will be avoided; while the dividing of the inch space of the spiral into several parts, enables us to give a great bearing surface to very shallow threads.

I give, in *Figure* 5, a drawing of the threads as I would form them for a six-threaded screw. They

Fig. 5.



have an .18 inch pitch, and a depth of .04 in., being .11 in. thick at the root or bottom, and .07 in. breadth upon the face. Threads of this shape may be more easily and exactly made than any other, as a large part of the surfaces left by the boring and turning tools requires no change from the screw-tool, but remains and forms the flat faces of both the male and female screws. By this means the gauged sizes and requisite diameters of both the body and the hoops are more easily ascertained and preserved, when the screw-threads are formed.

The depth of the threads given in this figure must be ample; for, as the threads, when once interlocked and in place, are kept in contact by the shrinkage of the hoops and the distension of the gunpowder, the idea of the outer threads slipping and riding over the inner ones, like a loose nut upon a screw bolt, is simply preposterous.

A mechanical equivalent for the screw-threads may be found in small circular prominences formed upon one surface, to fit into corresponding grooves upon the opposite surface. The principal objection to this mode of cramping or interlocking the surfaces will be found in the necessity of heating the hoop to a much higher temperature than is required with the screw-

thread, in order to expand it so that it may pass to its place upon the gun. These prominences and grooves, doubtless, might serve a better purpose than the mere roughness left by the turning tools, as now often used. I am confident, however, that no device can be made, superior to the screw-threads, and nothing better than this is needed.

The benefit, moreover, to be derived from making "the threads of the female screws sensibly finer than those of the male," must, I think, be evident after a little examination. By making this difference the $\frac{1}{1000}$th part, or perhaps a little more (that is, by making 1000 turns of the spiral of the female to occupy a shorter space upon the hoop by a $\frac{1}{1000}$th part than the same number of turns do upon the body), they will be more nearly equal when the hoop is expanded by heat, than if they had been formed of equal fineness or pitch. The hoop will, therefore, go more readily to its place when expanded, from bearing this finer thread. When the first layer is shrunk in its place, each hoop will be under a lengthwise strain; and, again, when the second layer is shrunk upon the first, the first layer, and, under it, the body of the gun, will be drawn together lengthwise, and thus the body will be guarded from cross-fracture, as it is guarded from longitudinal fracture by the circumferential strain of the same hoops.

Having thus exhibited the principles which should direct us in the construction of hooped cannon, and the experiments by which these principles are come at, I now proceed to describe the method of forging

the hoops, and of giving to them that combination of hardness, elasticity, and tenacity, which has been shown to be so important to the strength of the cannon.

To construct one of the hoops for a cannon of the size before mentioned, that is, of 14-inch caliber, the hoop having, when finished, 27.972 inches' internal diameter, and being $3\frac{1}{2}$ inches thick, and 15 inches long (or broad), I take a flat bar, say 14 inches wide, from half an inch to an inch thick, and of such length that, when wound into a coil, it shall form the thickness required for the hoop, after allowing for the waste in welding, forging, and finishing. After its ends have been scarfed to a long wedge form, it is to be heated to a low red heat, and then wound upon a cylinder of say 25 or 26 inches diameter, as a ribbon is wound upon a block. Next, it is to be heated in a proper furnace to a good welding heat, and then, being placed upon an arbor, or mandrel, of about 25 or 26 inches' diameter, and between proper dies, setts, or swages, it is to be completely welded, or the several layers or coils are to be made to form one piece. This may be done by compressing it with the swages, by a hydrostatic press, or by a steam hammer. After it is properly welded and condensed in this way, and has cooled as low as 600°, it is to be placed upon a cold arbor, or mandrel (shown, in section, at *A*, *A*, *Figures* 6 and 7), which is supported at both its ends by the upright studs of the heavy iron frame *B*, *B*. It is then to be hammered by the steam hammer *C*, until its internal diameter is enlarged to about 27 inches.

Fig. 6.

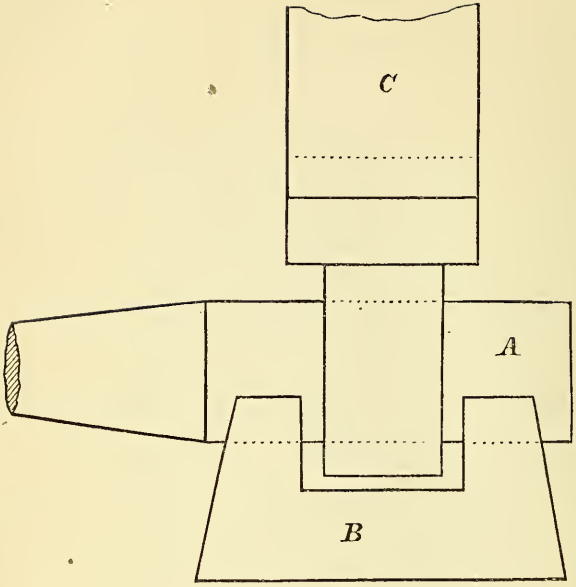
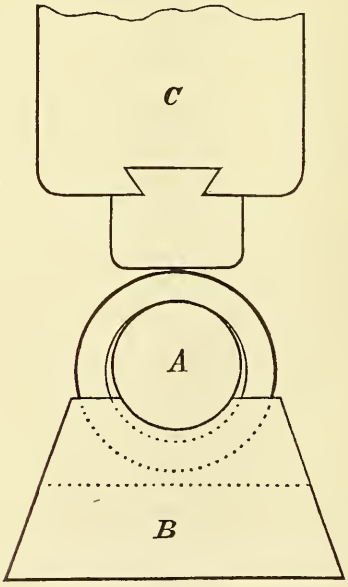


Fig. 7.



The last part of the hammering is to be performed after the hoop has become cold. Instead of operating in this way with the steam hammer, we may produce the same effect upon the hoop by a rolling-mill, in which the operating part of the rollers is made to project beyond the housings, or frame.

After the hoop has been condensed and enlarged in this way, it is next to be placed upon an annular anvil, *D*, *D* (*Figures* 8 and 9), and the segmental swages or blocks, *E*, *E*, are to be adjusted within it. These segments form a cylinder upon their outer surface, but inside they form a hollow cone. A solid conical plug, *F*, is fitted to be driven into this hollow cone within the swages. With this arrangement, the whole being under the drop or steam hammer *C*, the plug is driven by repeated blows into the hollow cone, by which operation the hoop is stretched sufficiently to destroy all conflicting strains or tensions that might have been produced in it by the hammering. The strain is thus reduced to a circumferential direction, and the hoop put as near as possible into the condition of the hard wire (as shown in *Figure* 2), after it had been subjected to the first series of strains (as shown in *Figure* 1).

The hoop may be stretched by this last operation the $\frac{1}{100}$th part of its diameter, and, if it is made of very soft and tough iron and has not been hammered very hard, much more than this quantity. The extent, however, to which this hammering and cold stretching may be carried, must depend upon the quality of the iron and the heating and working to which it has

Fig. 8.

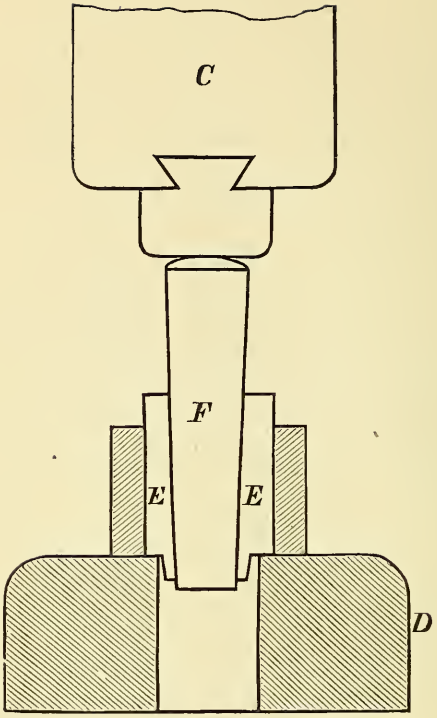
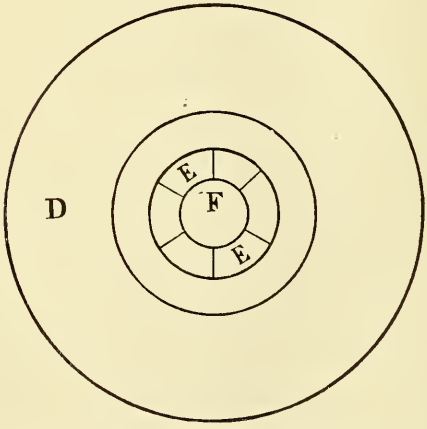


Fig. 9.



been previously subjected. It will be well, when the stretching is commenced, to have the hoop warmed up to 200° or 300°.

After the hoop has been prepared in this way by cold hammering and stretching, it is to be bored and turned; and, whether it is to be fixed to the gun by a screw-thread, or by any equivalent, it is to be carefully and equably heated to such a temperature (but never up to an annealing heat), as shall expand it sufficiently, and, in this state, is to be placed upon the gun.

In all the preceding computations of the force which the cannon is required to resist (both in this paper and in that to which this is intended as a sequel), I have considered the powder, when fired, as acting by a pressure generated with inconceivable rapidity, and with an intensity sufficient to produce the required velocity in the missile; — this velocity being produced by the pressure alone. I am fully aware, however, that the force thus produced, almost instantaneously, from a single point within the gun, does, and must, throw a shock upon, and a vibration through, the whole mass, the destructive effect of which must be provided against in addition to that of the mere pressure of the fired powder, if that pressure be supposed to act as the pressure acts in the hydrostatic press, for example, where it is raised and communicated slowly and gently to its object, thus producing its motion without violence or shock. Although we are without the knowledge requisite to subject to a rigorous computation the destructive ef-

fect of this shock and vibration from the discharge, yet it is necessary that a sufficient strength should be provided in the gun to resist it. Nor are we without the light of experience to direct us to this end; for, although it has not yet been determined, by direct experiment, what strength is required in a gun of say 14-inch caliber, in addition to that thrown upon it by the pressure of the charge, in order to withstand the sudden shock and vibration before mentioned, yet we have direct experiments which have determined this element in guns of smaller caliber. Thus the cast-iron 32-pounder, $6\frac{4}{4}$ inch caliber, if made of good iron, and in the usual proportions, that is, with walls of one caliber in thickness, has been proved, by the experience of ages, to be quite reliable for long-continued use with service charges.

Now, it was shown, in my former Memoir, that a maximum pressure, from the fired powder, of 920 atmospheres, will give a velocity of 1,600 feet a second to a 32-pound shot; and, further, that, computing the strength of the gun from the tenacity of the iron, taken at 30,000 pounds per inch, it is capable of resisting a force of 1,333 atmospheres; or, the strength of the gun is to the maximum pressure of the powder as 144 : 100. Hence, we have an excess of 44 per cent., which has proved sufficient to sustain all the extra violence from the shock and vibration occasioned by the suddenness of the discharge, from the heat, and from all other adventitious causes. It is furthermore shown, in the same Memoir, that a spherical shot of 14 inches' diameter will receive a velocity

of 1,600 feet a second, if fired from a cannon, the bore of which is 112 inches long from the seat of the ball to the muzzle, under a maximum pressure of 2,133 atmospheres. But we have seen, that a 14-inch gun, constructed with hoops as herein described, will sustain a pressure of more than double that required to throw the ball with 1,600 feet initial velocity. There can be no doubt, then, that, as 44 per cent. above the necessary powder pressure has, through long experience, proved sufficient, in the 32-pounder, to provide for the contingent strains from shock and vibration, 100 per cent. must be more than sufficient to provide against the same contingencies in the 14-inch gun; and, indeed, that 14 inches does not approach the size to which guns may be safely trusted, if constructed upon the principles, and in the manner, herein laid down.

Although it is hardly to be expected that the preceding method of cold working will impart to the hoops, if made of common iron, the elasticity and tenacity possessed by the wire used in the experiments herein related, yet, by the use of iron of superior quality, I think that that standard may be reached. But, should it be found, in the end, that 10 per cent. must be deducted from the tenacity of the wire, in computing that of the hoops, we shall still find the gun constructed in this way, for all that I can see to the contrary, *more than twice as strong as any hooped gun ever yet constructed, of the same materials, weight, and dimensions*; and, by the use of iron of a somewhat steely

character, or of some of the *low* steels, the standard of the strength of the wire may be much surpassed.

I cannot conclude this paper without observing, that, although in the Memoir formerly published no particular method of hardening the hoops was pointed out, and thus the process of cold hammering and stretching was omitted, still it was always my intention, whenever I should undertake the manufacture of hooped cannon, to prepare the hoops by some process of condensing and hammer hardening. So fully was I impressed, from my experience in the working of iron, with the importance of thus preparing the hoops, that, in 1862, when I had made an arrangement, with the Massachusetts Committee on the Defence of the Ports and Harbors of the State, for the manufacture of two hundred large cannon (an arrangement which was entirely approved by the Executive government of the State, and which failed to be consummated only by the rejection of the appropriation bill, in the Senate, by a majority of one), I visited several of the large machine-shops in the vicinity to find where I could best procure the construction of the steam hammer and tools for performing the operation herein described. My ideas (which were not then very definite) of the importance of subjecting the hoops, to be used upon cannon, to this condensing and hardening process, have been fully confirmed and defined by the experiments herein detailed; and the conclusions that I have drawn from these experiments will, I think, be assented to by any practical engineer who may take

the pains to examine them. Indeed, it seems to me remarkable, that, with all the attention that has been given to the subject of hooped cannon in Europe, as well as in this country, for several years past, the cause of the great defect, which it has been one object of this paper to point out and remedy, does not seem to have been discussed nor seen, although the defect itself has been made known by the bursting of such guns in so many instances as to have shaken, if it has not destroyed, the confidence of artillerists in them, when used with heavy charges. To avoid this defect, resort has been had to the use of *low* cast-steel, under the name of homogeneous iron; or to an adoption of the manufacture with wrought-iron, after the method invented and practised by me more than twenty years ago, and which I afterwards improved into the simpler and cheaper form so fully described in these Memoirs.

I may also observe, with regard to the theory of the strength of hollow cylinders, when exposed to a bursting force, that many changes to the original formulas of Mr. Barlow have been proposed as expressing more exactly the physical conditions of these cylinders. These changes, however ingenious or learned, are of very trifling practical importance in the manufacture of cannon. The omission of Mr. Barlow to consider the pressure, as acting as a crushing force upon the internal portion of the cylinder, and thus as aiding, to some unascertained extent, its action as a distending force, in rupturing the walls of the cylinder, was, I believe, first made known by me in my former Me-

moir. So, also, no writer or engineer has yet, so far as I know, perceived or shown, that the theory of the strength of hollow cylinders, as now generally adopted, is wholly inapplicable to cylinders or hoops made of malleable materials, such as wrought-iron or bronze; for the reason, that the inner portion of such a cylinder will, as shown by my experiments herein detailed, be permanently elongated or stretched circumferentially, without being ruptured or weakened until after the outside has given way; a fact entirely at variance with the foundation of the theory. For, the assumption, on which the whole theory rests, requires that the fracture shall first take place upon the inside of the cylinder; an assumption that can only be true in fact, when the cylinder is formed of a material which is unmalleable, that is, incapable of being elongated or stretched to any considerable extent beyond the limits of its elasticity.

ON THE

MEASURE OF THE FORCES OF BODIES

MOVING

WITH DIFFERENT VELOCITIES.

BY

DANIEL TREADWELL,

VICE-PRESIDENT OF THE AMERICAN ACADEMY, AND LATE RUMFORD PROFESSOR IN HARVARD UNIVERSITY.

[From the Memoirs of the American Academy.]

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By DANIEL TREADWELL,

VICE-PRESIDENT OF THE ACADEMY, AND LATE RUMFORD PROFESSOR IN HARVARD UNIVERSITY.

[This paper was read to the Academy in March, 1854, as here printed, except a few sentences since added by way of illustration (as that from Brewster's "Life of Newton"), and some trifling verbal alterations.]

Although the great controversy on the measure of the forces of moving bodies, which divided the investigators of mechanical science during a part of the seventeenth and eighteenth centuries, is no longer considered open, as a subject for scientific speculation or inquiry, by many of the leading writers of the present day, they having concluded that it has been exhausted, or rather that it had terminated in the discovery that the whole question was of a verbal rather than of a substantial character, I have yet ventured to present to the Academy a paper touching it. I am not aware that any one has heretofore followed the course of experiment, and the particular reasoning from it, which will be found in this paper,

though the force of the spring has often been appealed to by partisans on both sides of the controversy, as proving the truth of the standard which each attempted to establish. I shall be very willing, however, to forego all claim to originality, if what is herein presented shall be found to assist any one to a clearer understanding of a subject on which Newton and Leibnitz were divided. Notwithstanding the high authority which, in more recent times, has decided that their disagreement was rather one of words than of things, I cannot but consider it as substantial and irreconcilable, not only affecting all just conceptions of mechanical force, but leading even those who thus attempt to reconcile the opposing theories into very grave practical errors and contradictions.

Thus Dr. Lardner says ("Mechanics," chap. iv.): "If a cannon-ball were forty times the weight of a musket-ball, but the musket-ball moved with forty times the velocity of the cannon-ball, both would strike any obstacle with the same force, and would overcome the same resistance"; — a statement that denies to the musket-ball *thirty-nine fortieths* of its force. I do not cite Dr. Lardner as an authority of a very high order, but as a leading lecturer and a writer of standard systematic works. But no one will, I presume, object to Prof. John Playfair as a representative of the modern writers who hold to the merely verbal character of this controversy. He was

not only, according to Lord Cockburn (in the "Edinburgh Review"), "the best philosophical writer in the English language," but he made this controversy a subject of special study; and he came to the conclusion, that, if the proper precautions were taken in limiting the vagueness and ambiguity of the *data* there would be no difference in the practical applications of force, and "that the propositions maintained by both sides were true, and were not opposed to each other." But let us see how he succeeded in applying these not opposed theories. In his "Outlines of Natural Philosophy," his last systematic work, published many years after the assertions cited above, he says (Vol. I. p. 206): "If the sections of two streams be the same, the forces with which they will strike on planes directly opposed to them are as the squares of their velocities. For the force of a stream must be as the force of each particle and as the number of particles that strike in a given time. Now, the force of each particle is as the velocity of the fluid, and the number of particles that strike in a given time, the section being given, is also as that velocity. Therefore the whole force of the stream must be as the square of its velocity." Not only is the assertion, that "the force of each particle is as the velocity of the fluid," directly opposed to the theory of Leibnitz, but the theorem, that "the whole force of the stream must be as the square of the velocity," is equally contradicted by the experiments

of Smeaton. For, according to these writers, the force of each particle must be as the square, and that of the stream as the cube, of the velocity. Again, Playfair says (on page 216 of the same volume): "If the sections of two streams are the same, their forces will be as the squares of their velocities, or as the heights due to the velocity of the water, and the effects of the machines driven by them will be as the cubes of their velocities, or as the heights due to those velocities multiplied into their square roots." That is, *forces* which are known to us only as *causes* produce *effects* as much greater than themselves as the cube of a number is greater than its square.

With such instances of substantial and radical error, from substituting the conclusions of one theory for those of the other, how can it be said that the difference is merely verbal, or "that the propositions maintained by both sides were true, and were not opposed to each other"?

Again, in the late "Life of Newton" by Sir David Brewster, it is stated, that "Poleni had published an experiment which he considered as proving Leibnitz's assertion that the force of moving bodies is proportional to the square of the velocity, and not, *as is commonly thought*, to the simple velocity. Dr. Pemberton saw its insufficiency, and drew up a *refutation* of it." This being "communicated to Sir Isaac, he was so well pleased with it, that he called upon Pemberton at his lodgings, and showed him a refu-

tation of Poleni, by himself, grounded upon other principles." This *refutation*, as it is called, is published in the "Philosophical Transactions," and is intended to support in its fullest extent the Newtonian measure of force, viz. that of the simple velocity, against the measure proposed by Leibnitz. Here then we have Sir David Brewster, one of the greatest of living names in mechanical science, in one of his latest works, asserting that the force of a moving body *is commonly thought* to be as its velocity *simply*, and that the assertion of Leibnitz that the force is proportional to the square of the velocity was *refuted* by Dr. Pemberton, and again by Newton himself.

While a question of this vital character, affecting all the conceptions and many of the computations of force, is in this contradictory and cloudy state, ought scientific men to rest upon it, or to suffer it to rest, as a closed subject? The labor of preparing the following paper shows my own opinion upon this question.

It may be well, perhaps, before opening the particular course of investigation pursued in this paper, to state briefly the precise matter that formed the subject of this renowned controversy. Suppose, then, a body, as a stone, A, of a certain mass, to be thrown in any direction in space, with a certain velocity, it must move onward with a certain force.* Now if

* *Force* is the unknown cause by which a body resists change

another stone, B, having twice the mass of A, be thrown with the same velocity that was given to A, it must move with twice the force of A; for we may divide B so as to form two stones, each of which shall have a mass equal to that of A, and if thrown with the velocity of A, they must each have the force of A, and if each separately has the force of A, both, united to form B, must have twice the force of A. This is substantially the mode of reasoning used by Galileo to show that the mass of a body could not alter the velocity with which it would descend by its weight, when unsupported, to the earth; and it follows from this, that under a given velocity the forces of all bodies must be directly as their masses. If, however, instead of throwing different masses with one and the same velocity, we throw one and the same mass with different velocities, we search in vain for any reasoning of this simple and decisive kind to prove that the forces must be as the velocities, or to show the relation that one must bear to the other. For while we can thus unite two distinct masses, making them to coexist under a common velocity, we cannot unite two distinct velocities, making them to coexist in a common mass. With the hope, then,

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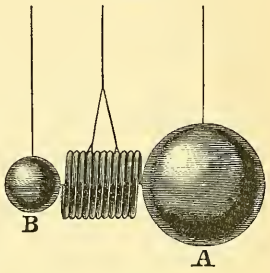
from, or produces change in, another body. *Synonyme*, Power. I shall avoid, if possible, the use of the words *momentum*, *vis mortua*, and *vis viva*, as they are often used and understood in such vague and indefinite senses as to obscure rather than to give any clearness to our conceptions in an inquiry like this.

of aiding to form a clearer conception of this subject, let me propose the following experiment.

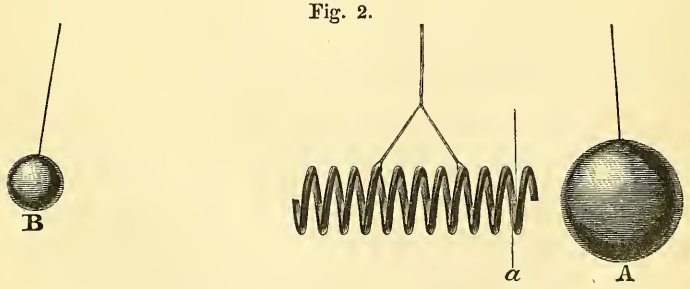
Take a spiral spring, formed of eleven turns of wire, coiled so as to leave an open space between each turn of the coil (as in Fig. 2). Let this coil be then pressed together as in Fig. 1, and place against

Fig. 1.



its ends respectively the weights A and B, suspended by cords, like pendulums. Let the weight of A be 10 pounds and the weight of B be 1 pound. On releasing the spring from its constrained condition it recovers, under the operation of its elasticity, its original form as shown in Fig. 2, while the masses

Fig. 2.



A and B are thrown, one to the right and one to the left, with velocities inversely as their masses, namely,

A with a velocity of 1, and B with a velocity of 10. All the force which had been applied to compress the spring, from whatever source it was derived, and which existed in the spring's elasticity, has now passed away from the spring, and been exhausted in giving motion to A and B. It has overcome, in those bodies, to a certain extent, their state of rest, and the force, *vis inertiæ*, with which they resisted all change of that state; and those bodies together now possess a force of motion, or inertia of motion, equal to the force of elasticity given out from the spring. We may therefore conceive that the force of elasticity in the spring has been transferred to A and B in the form of the force of the inertia of motion. This conception, while it violates no fact or result of experiment, will aid us in explaining them all.

The question now is, How much of this force has gone to A, and how much to B? Or, What is the force of A and of B respectively, at the instant they are discharged from the spring? One party in the controversy, who array themselves under the great name of Newton, determine the force of each by multiplying its mass by its velocity, simply, and find A, mass 10, multiplied by its velocity 1, to be 10; and B, mass 1, multiplied by its velocity 10, to be 10. That is, the force of the spring is equally distributed between the two bodies. They hold that this must be so of necessity; for the spring during

its action pressed equally to the right and to the left, equally against the bodies A and B. This pressure was continued an equal time upon both bodies, namely, during all the time of the spring's action. How is it possible then, say they, that a greater effect has been produced in one direction than in the other ?

This affirmation that the action is equal upon both bodies may be held as not merely derived from, but as constituting the substance of, Newton's Third Law, which asserts that " to every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts" ; and it is not to be denied that, so far as pressure constitutes action, this has been fully established by his citation of instances under this Third Law. But it by no means follows, because the spring maintains a like pressure by both its ends during the act of extending itself, that therefore its force is transferred equally to both bodies. The velocity with which this pressure overcomes the resistance opposed to it must be regarded, as well as the pressure itself; and indeed the whole controversy lies in determining the value that belongs to the velocity as one of the factors by which the force is produced; that is, whether this factor shall be taken in its simple form, a value clearly assigned to it by Newton in the Corollaries and Scholium of his Third Law; or whether a higher

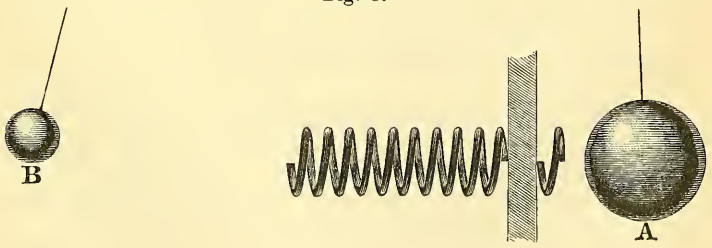
value, as its square, shall be given to it, as was first proposed by Leibnitz. Let us then see if, by tracing the course in which the spring elongates itself under different conditions, we can increase our knowledge of the transference of its force. By an examination of this subject, we shall find *that the spring acts upon each body with a velocity proportional to the resistance that it receives from the opposite body ;* and we shall find *that, as we increase the mass of either body, the effect produced upon the opposite body will be increased.* Thus, if we add to the mass of B, until it becomes equal to that of A, and let the spring expand as before, the velocities of A and B will be equal; the velocity of A being more than double (as $\sqrt{5.5}$ to $\sqrt{1}$) what it was before the size of B was increased. The force expended, namely, the elastic force of the spring, has been the same in both cases. Will it be said that it has been distributed in the same proportion to the two bodies, when A, the mass of which has not been changed, has had its velocity increased in this essential degree? And yet the Newtonians would make it the same; namely, half to each body in both instances.

We may, I think, obtain a clear conception of the action of the spring, if we consider it as depending, for its effect on each body, upon the degree of immobility which it finds in the opposite body; and hence *the force communicated to each body will depend upon the resistance of the inertia of the opposite body ;* or,

through the action of the spring, the inertia of rest in each body is transferred as an active force in the motion of the opposite body. In the case before us, the body A having an inertia 10 times as great as that of B, the force communicated to B by the spring is 10 times as great as the force communicated to A. To show this more clearly, let us attend to the exact course of the action of the spring. It will be found, if proper means be taken to mark the motion of the spring (Fig. 1) in its course of extending itself, that, during this extension, 10 of the rings of which it is composed open to the left, in the direction of B's motion, and only one in the direction of A, while the point *a* (Fig. 2) has remained at rest. The spring has acted from a plane, passing through the point *a*, as from a base, to the right and to the left. Now will any one say, that, when 10 out of 11 parts of the spring have acted wholly in the direction of B, the effect of the spring has been equally distributed between A and B?

Suppose we cut the spring in two at the point

Fig. 3.



a, and fix the cut end of the larger part to an immovable plane, as in Fig. 3, and, placing the ball B

against it when compressed, suffer it to extend itself against B. The velocity of motion that it will communicate to B will be precisely equal to that produced under the conditions of Figs. 1 and 2; and if we take the remaining coil of the spring, and fix it to the opposite side of the plane, as in Fig. 3, and suffer it to extend itself, it will produce the same motion in A that was produced in the first experiment. Now it must be evident that the 10 rings of the spring contain 10 times as much elastic force as the 1 ring, and that, as no motion whatever is communicated to the plane by their action, all the force of each spring must be communicated to the bodies A and B, against which they act respectively; and as these forces are to each other as 1 to 10, so the forces of A and B must be as 1 to 10. But the velocities of A and B are to each other the same that they were in the first experiment. Hence it follows, that the forces produced in A and B by the unbending of the spring in the first experiment were not equal, but that B received 10 parts of the force and A 1 part; and this distribution corresponds exactly with the product of the mass into the square of its velocity.

For the mass of A $= 10$ and its velocity $= 1$; then $10 \times 1^2 = 10$ for the force of A; and the mass of B $= 1$ and its velocity $= 10$; then $1 \times 10^2 = 100$ for the force of B.

We shall find, moreover, that the forces of A and

B, under the velocities produced by the action of the spring, are to each other inversely as the masses of A and B; that is, at the instant that they leave the spring,

Force of A : Force of B : : Mass of B : Mass of A.

Or, the force of B is as much greater than the force of A as the mass of A is greater than the mass of B. Again, if we neglect entirely the masses of A and B, or the quantity of the mass in each, we shall find that their forces are to each other as their velocities directly, and not as the squares of their velocities. Thus, we have found the force of B at the instant that it leaves the spring to be ten times as great as that of A. This was found by multiplying the mass of each into the square of its velocity. But the velocity of B is ten times as great as that of A. If therefore we neglect the masses, as factors, with both bodies, and take the force of each, not as the square of its velocity, but as its velocity simply, we have the same comparative results; that is,

Force of B : Force of A : : Velocity of B : Velocity of A.*

This last statement is not given as favoring the Newtonian measure of force. For the mass of the body is, in that, always taken as an element or factor of the force, and it can be struck out only in a case like the one here stated; where, on striking it out,

* Indeed, this amounts to no more than dividing the two sides of an equation by the same number.

the value of another factor of the force, namely the velocity, is evolved from the square to its simple power.

It cannot fail to be understood, that whenever two bodies, as A and B in the preceding example, receive the action of elasticity impelling them in opposite directions, the neutral point, as at *a*, Fig. 2, will be placed so as to divide the elastic force into two parts, having the same proportion to each other that the parts into which a line connecting the centres of gravity of the two bodies will be divided by their common centre of gravity. Thus in the example herein given, if A contained 100 times the mass of B, the spring would be divided by the point *a* so as to give 1 part to A and 100 parts to B ; and if the mass of A be made infinite with regard to B, so as to be immovable, as in the plane, Fig. 3, the point *a* coincides with the end of the spring, and all the force is communicated to B.

A very striking example for illustrating the principles of this analysis, and displaying the force of elasticity in its highest form, may be imagined under the following order of preparation. Divide the charge of powder, intended for a piece of ordnance, by a diaphragm of iron, or any substance that will stand the heat, no matter how light and thin it be, into two parts, that shall be to each other as the weight of the gun is to that of the ball. Load the piece by placing the end of the cartridge containing the

smaller portion of the charge at the bottom of the chamber, the ball being placed over the larger portion of the charge. Now if the fire be communicated to both parts of the charge at the same instant, the diaphragm must, however light, remain perfectly stationary in space, being subjected to equal pressures in opposite directions upon its two sides, while the gun and the ball are driven from it in opposite directions, with velocities inversely as their weights. Here, as the cannon is often 200 times as heavy as the ball, the quantity of powder before the diaphragm, and actually expended in producing the motion of the ball, is 200 times as great as that expended in producing the motion or recoil of the gun, though the pressure upon both is the same in intensity and in time; but the quantity of the force communicated to the ball must be, under these conditions, directly as the powder expended to produce it; and yet if we take the force of the ball and that of the gun in its recoil, respectively, as the product of the mass into its velocity simply, we shall make them equal, one to the other; that is, 1 oz. of powder acting from one side of a plane, equal to 200 oz. acting from its opposite side. But, by the measure of the square of the velocity, we have, mass of ball 1, velocity 200, and $1 \times 200^2 = 40{,}000$ for the force of the ball; mass of gun 200, velocity 1, and $200 \times 1^2 = 200$ for the force of the gun's recoil; which corresponds exactly with the expenditure of

the powder. It may again be observed that these forces correspond, inversely, with the masses; for 200 : 40,000 : : 1 : 200.

It can hardly be necessary to remark, that in any of the preceding instances we may reverse the direction of the motion, and consider the bodies as made to approach towards each other, rather than to recede from each other. Thus if A and B, when placed asunder as in Fig. 2, are drawn towards each other by a distended spring, or by any kind of attraction, or gravitation, inherent in the bodies themselves, the force excited in, or transferred to, each will be inversely as the masses of the bodies respectively, and this will be the case whether the elastic or attractive force be constant or variable. Hence, if the orbital motions of a satellite and its primary were destroyed, they would approach their common centre of gravity with forces *directly* as their velocities and *inversely* as their masses (*see* p. 15); and if another body were placed at their point of meeting, such body would receive a shock from the satellite as much greater than that received from the primary, as the velocity of the satellite was greater than that of the primary, or as the mass of the primary was greater than that of the satellite.

Hence in all those operations in the arts by which the form of unelastic bodies is changed by collision or percussion, as in the action of the hammer or axe, the efficiency of the instrument depends upon

the inertia of the body against which it acts. Thus, if a block or anvil be suspended by a chain, or made to rest upon a spring, and a piece of lead or any soft and unelastic body be placed against or upon it and struck by a hammer, the force of the hammer will be divided between the lead and the bed or anvil; that is, in changing the form of the lead, and in giving motion to it and the anvil; and the distribution of the force, or the proportions which go to the different bodies involved in the action, may be found as follows: —

Let the mass of the hammer $= m$.
Its velocity before the blow $= v$.
Its velocity after the blow $= v'$.
The mass of the bodies struck $= m'$.
Velocity after the stroke $= v''$.

Then the *force* of the hammer before the stroke will be $m\,v^2$. Of this force there will remain in the motion of the masses after the stroke

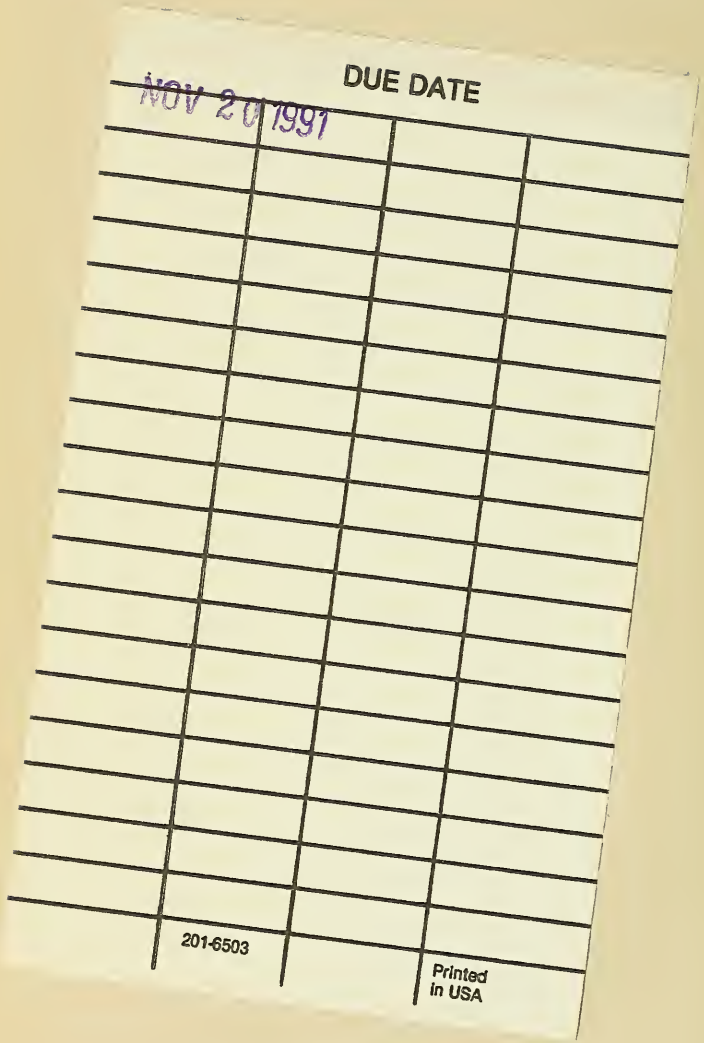
$$m\,v'^2 + m'\,v''^2$$

and $m\,v^2 - m\,v'^2 - m'\,v''^2$ must be *absorbed* in changing the form of the lead.

If we neglect entirely the effect of elasticity, which we may do for most practical purposes, in both masses, then when m and m' are equal, one quarter of the force will remain in the motion of m, one quarter will be communicated to produce motion in m', and one

half will go to change the form of the soft body. So, if the mass of m' be infinitely greater than that of m, or, not being greater, if m' be made to move in a direction opposite to the motion of m, and with a velocity such that m' and m remain at rest after the collision, then the whole force will be absorbed in changing the form of the soft body.

What is here stated may be applied to the whole subject of percussion or collision.



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